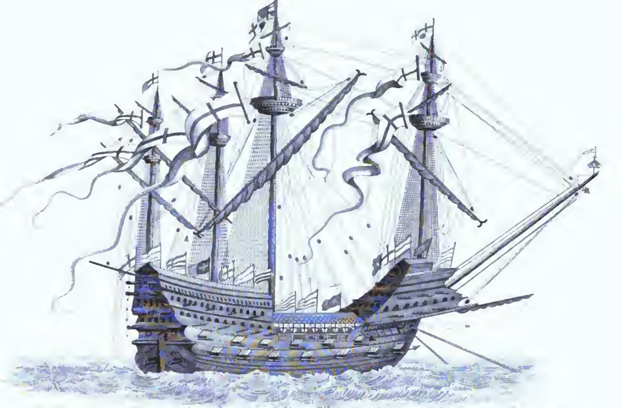

# Treatise on the Theory and Practice of Naval Architecture

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# TREATISE

ON

# NAVAL ARCHITECTURE.

BY

A. F. B. CREUZE, ESQ.

# TREATISE

ON THE

# THEORY AND PRACTICE

OF

# NAVAL ARCHITECTURE:

BEING THE ARTICLE "SHIP-BUILDING"

IN THE

ENCYCLOPÆDIA BRITANNICA, SEVENTH EDITION.

BY

AUGUSTIN F. B. CREUZE,

MEMBER OF THE LATE SCHOOL OF NAVAL ARCHITECTURE,
PRESIDENT OF THE PORTSMOUTH PHILOSOPHICAL SOCIETY, AND EDITOR OF THE PAPERS
ON NAVAL ARCHITECTURE.

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# INTRODUCTION.

The Proprietors of the Encyclopædia Britannica having resolved on printing the article "Ship-Building" as one of their separate Treatises, it may not be deemed superfluous to append to it the following short explanatory introduction. The principal inducement to this determination on the part of the Proprietors, is the great scarcity of works on Naval Architecture in the English language. It may fairly be objected, that a Treatise, written in conformity with the restrictions of space necessary to the articles of an Encyclopædia, must be inadequate to supply this desideratum, and must be deficient in professional detail. Although this objection is to a certain extent admitted, it is doubtful whether the increased utility of a more voluminous work would have been commensurate with the additional cost, or whether a Treatise which aims at the popular elucidation of general principles is not likely to be of more use, and more adapted to win attention, than a work of elaborate disquisitions; a work, in fact, containing not only the principles of the science, but details concerning the application of those principles, together with all the technical minutiæ of the art of ship-building, uninteresting to all but practical men.

The principal additions which might have been made would have consisted of examples of the various calculations necessary to the scientific formation of the design of a ship, more voluminous tables of dimensions of ships of all classes, and for all services, and corresponding tables of scantlings of their various component parts.

With respect to an example of the method of making the whole of the calculations, it certainly would have appeared a most imposing mass of arithmetical labour, and might have saved some little thought to an inattentive student. This Treatise will, however, have failed very materially in the object for which it was written, if the description of the manner of performing these calculations should not be sufficient to enable an attentive student to complete them without the aid of an example. Should an example be deemed indispensable, one may be found at the close of Professor Inman's notes to his translation of the *Architectura Navalis Mercatoria* of Chapman; a work that should be in the library of every person wishing to study naval architecture. It certainly is requisite that the student should have at least the preparation of elementary mathematical knowledge. Without this preliminary acquirement, it would be impossible for him duly to comprehend the object or the nature of the work on which he was employed, or to have any confidence in his results when they were obtained. With comparatively elementary mathematical knowledge, he may not only understand the explanation of the manner of, and the reasons for, performing the calculations, but also apply them to particular cases. It is perhaps necessary to state, that little more than what may be considered elementary knowledge of mathematics will be required in reading the whole of the Treatise. In the mathematical investigations of the questions involving the mutual dependence of the water on the hull of the ship, and of the wind on the sails, a knowledge of the simple problems which embrace the principles of the composition and resolution of forces is necessary. But no person unacquainted with these principles can be said to be competent to direct works of importance in any branch of mechanical art, and therefore it cannot be too great an assumption to presuppose that persons wishing to understand what naval architecture is, still more to become naval architects, are acquainted with them. Also, since naval officers cannot enter into the reasons for the beautiful manœuvres incidental to the practice of navigation, if unacquainted with these principles, the same argument may be adopted to justify the supposition that they also are in possession of such preliminary knowledge. Therefore, should they be induced to read that portion of the present Treatise in which these questions are involved, they will meet no difficulty which attention will not overcome, and will find that the theory of seamanship is most intimately connected with the theoretic studies of the naval architect.

With respect to dimensions of ships, a sufficient variety will be found in the following Treatise, to serve as data in applying the reasonings and investigations that are contained in it to practice. Again, with regard to the addition of schemes of scantlings, the object of that portion of the work which is devoted to practical ship-building has rather been to strike out a new method of treating the subject, than to follow the usual routine of giving long details of scantling, sizes of fastenings, and minutiæ of workmanship, which would have little to recommend them beyond others that are already in print. The course adopted has been to establish a few leading principles as guides to the practical ship-builder, by which to determine the nature of the strains and stresses to which a ship as a whole, and the various combinations of its structure as parts of that whole, are subjected. And the reason for pursuing this plan has been the conviction, that it is of greater importance, in a practical point of view, to determine the nature of the stress, and how most advantageously to place a fastening, a tie, or an abutment, to oppose that stress, than to accumulate tables of scantlings to those which are already to be found in print; at least the adoption of this course is considered as being more likely to conduce to an economical acquisition of strength. In fact, the tremendous power of the waves of a tempestuous sea, and the dangerous, and often, in despite of all precautions, fatal effects of a vessel's grounding or striking on a rock, must make it evident that in many cases it is not only utterly impossible to estimate the limits of the strain which would have to be resisted, but impracticable to accumulate an amount of strength sufficient to preserve the vessel from destruction.

In the generalizations of this part of the Treatise, the endeavour has been to point out those portions of the structure that are capable of being adequately strengthened to resist the usual strains to which they will be subjected; also those parts in which strength may be most advantageously accumulated as a reserve, and those other parts which it is necessary to strengthen by support to be derived from these stronger portions of the structure. By this means it is conceived that a ship of uniform strength or power of resistance to external force, and to strains from excess of cargo, and from stress of weather, may be insured. It is presumed that a ship of adequate strength against all but the unavoidable contingencies already mentioned, can scarcely fail of being built, if any of the recognised schemes of scantlings be taken as the basis of the dimensions of her timbers, and the reasonings of the Treatise be considered in their disposition, or in any modification of them.

The only guide in the English language for the details of the system of practical building which is pursued in the Government dock-yards, is "Fincham's Outlines of Ship-Building." Mr Fincham, now the master shipwright of Chatham dock-yard, was, almost from the foundation of the late School of Naval Architecture until its abolition, the instructor of the students in practical ship-building. He has had, therefore, in addition to his own previous knowledge acquired in a dock-yard, many years of that best of all experience, the experience acquired from teaching; and the existence of his work renders the absence of similar details in the present Treatise of comparatively little importance. It may however be necessary to observe here, that much information in practical building which has not been embodied in the letter-press of the following pages, will be obtained by referring to the plates.

It will be observed, that in the pages of the following Treatise, whenever the details of practical building incidentally involve the mention of modern deviations from ancient customary combinations or methods of fitting, all discussion as to who were or who were not the original proposers has been avoided. A contrary course would have been entering into controversial discussions that would have been completely at variance with the intention of the Treatise.

Although the portion o fthe article which has been devoted to the subject of laying off ships on the mould-loft floor is that which is the most abridged, in consequence of want of space, it is considered that enough of the principles are explained to render any particular application of them, beyond the examples given in the text, a task of very little difficulty. It will be seen that in several instances, although the methods of laying off certain portions of the vessel are illustrated by the plates, the text which referred to these illustrations has been omitted, to bring the matter within the limits assigned. The laying off was selected for abridgment, because, although there are no works in the English language that treat either of the theory or the practice of naval architecture, on the plan which has been attempted to be pursued in this Treatise, we possess several works upon laying off. Of these the best are undoubtedly Stalkaart, Steel, and Fincham, Mr Fincham's having the advantage of being the most modern, and adapted to modern ideas and improvements.

It has not unfrequently been objected to works having for their object the diffusion of information on naval improvement, that we, as Englishmen, should be cautious in publishing such knowledge, but should rather endeavour secretly to avail ourselves of it, because an opposite course might tend to diminish the superiority of our navy, by increasing the efficiency of that of our rivals. We do not believe that this conclusion is at all correct, and we shall presently endeavour to establish the position we thus assume. But even were it absolutely and incontrovertibly correct, it can only be applied to the question of the improvement of naval architecture, by the advocates of a most selfish and narrow-minded policy. A broad distinction should be drawn between the means of preservation and the means of destruction. The means of preserving human life should be considered the common property of all mankind; the means of destroying it, unless the national safety should demand it, a secret neither to be divulged nor used. Every man who can in any way add to the security with which the sea may be navigated, is as much bound to diffuse such knowledge, as he would be to save a drowning man from the waters. Whether the additional security be attained by the improvement of the chart, which is the guide to navigation, or of the chronometer and sextant, which render that guide available, or finally of the ship itself, the additional security is a boon to mankind, and the promulgator or the inventor of the means by which it is attained is surely a benefactor to his species; because, in proportion as the means and aids of navigation are perfected, its dangers are diminished, and in proportion as the knowledge of the methods for improving them is diffused, so is the whole family of man benefited, and the natural state of society, which must be presumed to be a state of peace and good-will, ameliorated.

On the other hand, as far as the question of state-policy is involved, it should be remembered, that although we may avoid the discussion of questions on the improvements of naval architecture among ourselves, we cannot prevent other nations from discussing them; the necessary result of which would be, and we may almost say has been, because, to a certain extent, this policy has been pursued in England, that they would progressively improve, while we should be confined to the slow and uncertain developments of knowledge, which are the necessary consequences of being restricted within the bounds of an ever-commencing, because an uncommunicated, or, at the best, an imperfectly communicated experience. It may be said that we can profit by their advance; but is this assumption correct? If foreign nations follow that more enlightened system of policy which encourages the application of other and more abstract sciences to the investigation of the phenomena of naval architecture, and are thus able to arrive at and to establish correct conclusions, to be transmitted as sure bases for further researches, while we, on the contrary, remain ever restricted to that modicum of knowledge, or of experience, as it is called, which is the result of a lifetime of error, how are those men to be formed who would be capable of profiting by the advance made by the foreigner? Where are those men who can even be fitted to comprehend in what it consists sufficiently to render it available to our wants? Be this as it may, it is too notorious, that during our wars with France and Spain, we have never yet been able to derive the advantage of any considerable increase to our knowledge in the principles of designing ships, from the numerous fleets which have fallen into our hands, although it is equally notorious that their ships were superior to our own. The excitement of emulation is deadened in the mere copyist, and one of the chief incentives to improvement is lost in the servile office of imitation.

It may possibly be thought, that a very large proportion of space is appropriated in this Treatise to the historical sketch of the progress of naval architecture. It was found however impossible to avoid this; nor perhaps is it to be regretted, for it is a great point towards the advance of any branch of knowledge, not only to ascertain the existing amount of that knowledge, but also the various steps by which that amount has been obtained, and the reasons why it was not sooner obtained. We are prone to wonder, when we look back from the present comparative perfection of the various sciences, through long centuries of delusion and of ignorance, to their rise, and trace the wearisome and feeble steps by which that perfection has been attained; and we are astonished that such apparently trifling impediments should have so long delayed their progress; but on reflection we shall find, that the principal reason for the various delays, interruptions, and even retrogressions, which have, to a greater or less degree, been attendant on the progress of the whole of them, was, that in many instances the apparent advances in the path of improvement were not based on knowledge sufficiently profound. Thus, although in that most sublime and most perfect of all sciences, astronomy, amazing discoveries had been made through the persevering analyses of such men as Hipparchus and Ptolemy among the ancients, and Copernicus, Tycho Brahe, Kepler, and Galileo, among the moderns; it was not until the discovery by Newton, of the laws of gravitation, that each fresh investigation led to an assured advance in our knowledge of the universe. Again, in tracing the history of naval architecture, how long was its progress delayed? And how vast must have been the loss of human life, merely from the ignorance that existed among ship-builders, of that problem which drew forth from Archimedes the joyful ejaculation, "I have found it! I have found it!" upwards of two thousand years before Sir Anthony Deane first, in England, applied it to ship-building?

The science of naval architecture—for as a science it must now be treated, to enable it to respond to the requirements of the present day—cannot be said to have been even in its embryo until the discovery of the compass; for until then little more than boats were adequate to the most extended wants of navigation. This discovery was made, according to the received opinion, about the year 1300, though there appears to be good reason to believe, that the directing power of the magnet was imperfectly known, and partially applied to the purposes of navigation, for nearly a century previous to this date. Be that as it may, we have tolerably succinct histories of nautical adventure from that period until the present; and the result of an investigation as to the diminution of sea-risk from the time of Gioia to that of Drake, from thence to that of Anson, and again to the present epoch, would be not merely a curious, but an instructive document, because it would serve as a practical illustration of the advantages resulting from the improvement which has gradually taken place, and because also we might fairly draw an induction from what has been done with but very imperfect means, to what might have been done had those improvements been anticipated by centuries. And it is not unreasonable to presume that many of them would have been so, had it chanced that the aid of a scientific system of investigation could have been as early applied to naval architecture as it has been to civil architecture.

We may fairly say that there is no machine upon which more varied or more extended knowledge may be advantageously bestowed than upon a large ship, to insure perfection in its several requisites, as a machine for locomotion, for burthen, for war, for strength, and for durability; and we grieve to say that we know of none upon which so little has been considered necessary, at least in this country. It was at once admitted that Sir Christopher Wren, who, Newton has said, was one of the greatest geometricians of the age in which he lived, was alone equal to the task of rebuilding St Paul's; and both before and since that time there has not been a public building, nor even a mansion, erected, without the aid of men of scientific education./A first-rate man-of-war is as a cathedral in its immensity and in its expense, and a loaded Indiaman is even yet a more costly hazard: add to this the inappreciable amount of human life with which each is freighted, and well may greater skill, profounder science, and higher intelligence, be each and all tasked to insure the safety of the precious charge, which, unlike the earth-supported cathedral, is almost a baseless fabric, and is therefore subjected to far more complicated and more violent trials than can be encountered by any structure on a firm and unyielding foundation.

The naval architect should prepare the ship ready for the hands of those who are to navigate her. It is the ship, with her masts and sails adapted for her, and her stores and their stowage arranged, which is required from him. That these objects may be all achieved, and perfect in their kind, not only would the most profound theoretic knowledge be required, and that too in several sciences, but there must be a vast fund of sound practical experience based on that theoretical knowledge. The naval architect should be not only a mathematician and a chemist, but he must be a thorough practical mechanic.

A ship, whether destined for war or commerce, ought to be able to bear a certain determined lading, and be sufficiently capacious to afford ample accommodations for her crew, with all the contingencies involved in the consideration of their health and comfort. She must carry the cargo with ease to herself; the artillery in a perfectly efficient state, whether space for working the guns, or the height of those guns above the surface of the sea, be considered. She must be so formed that she shall be able to make her passages with velocity when the wind is favourable, and contend with it advantageously when it is unfavourable. The ship must be capable of being worked with ease, rapidity, and certainty, however adverse the circumstances may be under which the manœuvres are performed; for it will sometimes happen, that the more unfavourable the circumstances are, the more imperative is this necessity for success. She must have great stability, or the power of resisting inclination, and of restoring herself to an upright position when inclined; and this must be so nicely graduated and adjusted, that the perfect safety of the vessel may be insured without any injurious strain being brought upon the masts or rigging by an excess of this resisting power. She must be able to sail over rough seas without any injury from the pitching or rolling motions which will ensue, and without the hazards to the crew, to the vessel, or to the cargo, which would result from a tendency to ship seas when thus situated. Her masts must be so proportioned that they shall be sufficiently strong, taking into consideration the support they derive from the rigging, to resist the strains to which they will be subjected, and that without being so heavy as to diminish unnecessarily the stability of the ship, or require superfluous lading from extra ballast. The masts must be lofty enough to spread an adequate surface of canvass to furnish the propelling power, and, at the same time, be so placed and so proportioned to each other, that this propelling power may be readily converted into a series of mutually counteracting or co-operating forces to insure quickness of manœuvring. The hull must be perfectly impervious to the water, otherwise the cargo or the stores will be subjected to damage, and the ship to premature decay. All the various parts must be so put together that the whole shall compose a structure of uniform and adequate strength, and this not only when the vessel is new, but for so long as the materials of which she is constructed will endure. She must be composed of such materials, and those materials must be so arranged, that there shall be no injurious combination inciting premature decomposition or decay.

One great inconvenience, arising from the absence of any thing like a systematical pursuit of the study of naval architecture in this country, is, that there is very little traditional knowledge as to the various attempts at improvement which have been made. This may perhaps be best illustrated by an example. Could it have been possible that there should have been an official receptacle for this traditional knowledge as early as the sixteenth century, the improvements in shipping, resulting from the system of diagonal trussing, would certainly not have been so long delayed; for its advantages were evidently suspected even at so early a period as that. But for an instance which may be traced more particularly, and which more decidedly points out the advantage of records of experiments when in the hands of persons competent to the task of judging of their importance, and of drawing instruction from them, we may take an incident recorded in the historical portion of the article. The Romans sheathed their ships with lead, secured on the bottom by copper nails. In modern naval history, the Spaniards, according to Navarrete, first attempted this in 1514. The first ships sheathed with metal in England were those fitted out in 1553 to discover a north-east passage to China, or, as it was then called, Cathay, and placed under the command of Sir Hugh Willoughby. This was the expedition in which Richard Chancelor was pilot-major, and which ended in the melancholy loss of Sir Hugh Willoughby, and in establishing the fame of Richard Chancelor as the discoverer of Russia. Lead sheathing was again tried in 1671 on the Phœnix, and between that date and 1690 twenty ships were so sheathed. It was then discontinued; but in 1768 the Marlborough's bottom was covered with lead, which was removed after a two years' trial. There is then another long interval until 1833, when lead sheathing was tried on the bottom of the Success, in Portsmouth harbour. Now, had these various experiments been on record, with the reasons of their failure, those causes of failure would not in all probability have been repeated in each successive experiment, and certainly the lead on the bottom of the Success would not have been secured with iron nails. It is not improbable also that, centuries ago, some method would have been ascertained of advantageously applying that less costly metal, lead, to the bottoms of hulks, and all stationary vessels, and thus many hundreds of tons of copper would have been saved to the nation, by a lesson first taught by the copper nails in the sheathing of a Roman galley.

Before closing these few prefatory remarks, it may be useful to state concisely the characters of some of the principal works to which the student desirous of information on the subject of the theory of ships, or of the art of ship-building, may address himself.

The English works are few. The earliest English writer on the subject was Sir Walter Raleigh, who left two discourses on nautical affairs, from which some interesting extracts will be found in the following pages. The celebrated Samuel Pepys, who was secretary to the Admiralty in the reigns of Charles II. and of James II., is recorded to have written a work entitled *Architectura Navalis;* but the writer of this article has never been able to learn further of it than its bare name, nor indeed even to authenticate the fact of its publication. There appear to have been several works published in the early part of the last century, by shipwrights and mariners, in which geometry, trigonometry, mensuration, tables of squares and cubes, rules for extracting roots, gunnery, navigation, land and sea surveying, nautical astronomy, and ship-building, are mixed together " in most admired disorder;" but few of these are now to be met with, unless it be in the libraries of the curious. Among those which are occasionally to be procured, that of the earliest date is called the " Ship-Builder's Assistant, by William Sutherland, Shipwright and Mariner." It contains minute details of the practice of building and rigging ships at that period, and also one of the earliest glossaries in the language of the terms of naval art. The date of publication is 1711. The Seaman's Dictionary, by Sir Henry Manwayring, knight, was of an earlier date than this, it having been published in 1670. There appear to have been three editions of the Ship-Builder's Assistant, therefore its fame must have been considerable. The same author published another somewhat similar work in 1717, under the title of the " Mystery of Ship-Building Unveiled." But neither of these books is at all to be compared to the next in the series, " A Treatise on Ship-Building and Navigation, by Mungo Murray," a working shipwright in the government employ. It contains short treatises of geometry, trigonometry, mensuration of superficies and of solids, and logarithms, an explanation of the method of laying off on the mould-loft floor, and several mechanical methods of designing the bodies of ships: to these are added, treatises on land-surveying, geography, and navigation; and an appendix, containing an abridgment of the French works on naval architecture, by Du Hamel de Monceau, and by Bouguer. Mungo Murray was most undoubtedly a man of thought and ability, and his acquirements were very far superior to his station. Had he been advanced in the service, it is more than probable that his country would have had ample reason to be grateful to him for the benefits which he would then have had the power, as he certainly had the ability, to render her. His book is one of those which our great-grandfathers apparently delighted in; but after a lapse of nearly a century, though interesting, it is not a book to recommend to the modern student, excepting for the translations, in the default of a knowledge of the French language.

Stalkaart's work on laying off has been already sufficiently noticed, it being now supplanted by that of Fincham at a much more moderate price.

A Treatise on Naval Architecture, by William Hutchinson, mariner and dock-master at Liverpool, 1794, is the work of a very shrewd and observing man. It may be taken as a very fair sample of the degree of knowledge which may be attained by such a class of men, resulting from their long experience as seamen, but which is almost always hampered by their adoption of some particular views or dogmas, in order to strengthen which they are liable to pervert all their reasonings. As long as the works of such men are studied for the facts which may be recorded in them, they are valuable, because generally only such facts as are worthy of notice are recorded. It is a book which may be read with interest by the naval architect. It treats also of practical navigation, and on the defence and attack of ships. William Hutchinson was an old privateer's man and merchant mariner.

The Elements and Practice of Naval Architecture, by David Steel. This is a compilation by a bookseller; but it has been made with considerable ability, and he has embodied in the work a great deal of useful practical information on ship-building, and a very good treatise on laying-off ships on the mould-loft floor. The tables of dimensions and scantlings are by far the most voluminous in the language. There is also a large folio of plates, consisting of drawings of ships of all the classes in the royal and mercantile navies at the date of publication, that is, in 1805. There are several other smaller works compiled by or written for Steel. The Shipwright's Vade Mecum may be called an abridgment of this larger work, which is in the quarto form. He also published a valuable work, in two quarto volumes, on Rigging and Seamanship. In 1805, a Prospectus of an intended work on Naval Architecture, in all its branches and ramifications, was published by Alexander Mackonochie, Esq. of Baypoor, near Calicut, on the coast of Malabar; and had the work itself appeared, if we may judge by the talent and research apparent in the Prospectus, it would probably have left nothing further to be desired, but would have equalled, if not excelled, any work on naval architecture that has yet been written, not only in England, but in Europe. The Prospectus, which consists of about fifty closely printed quarto pages, is of itself an admirable essay on the various subjects for inquiry which suggest themselves as being involved in the theory of ships, and the practice of shipbuilding, interpreting these two branches of naval architecture in their most extended signification. When the author of the present Treatise was editing a work called "Papers on Naval Architecture," he made several ineffectual attempts to ascertain the fate of the papers of the late Mr Mackonochie, under the hope of being able to rescue some portion, at least, of the works of this gentleman from the oblivion to which it is to be feared they are destined.

To this list of books may be added a translation of Euler's "Complete Theory of the Construction and Proprieties of Vessels." This may be called an abridgment of his celebrated work *Scientia Navalis.* The translation was made from the French, by Colonel Watson of the Royal Engineers. Chapman's "Area of Sails" has also appeared in the English language, but is so very scarce that it may be said to be found only in the pages of the Papers on Naval Architecture, in the ninth number of which it was reprinted, in order to preserve so valuable a work from being utterly lost to English readers.

The more modern works on naval architecture which have appeared in England will be found to be sufficiently mentioned in the following Treatise to enable the reader to form his own opinion as to their respective values. The same observation will apply to those foreign works which are most worthy of the attention of the student; and it need hardly be mentioned here, for the humiliating fact is sufficiently notorious, that it is to these external sources that the student in naval architecture must address himself, if he intends to make himself fully master of all the higher questions in his profession. The following pages have been written with the hope that they may in some measure obviate this necessity; and although at the same time some things in them may be new, and the illustrations of some already established principles condensed, it cannot be supposed that so limited a number of pages contains sufficient to preclude the necessity of a more extended and varied study. The utmost that the present Treatise can pretend to, and all that the author hopes to have attained, is, first, that it may be considered as a synopsis to the theory and practice of naval architecture; and, secondly, that it may be the means of attracting more attention than has hitherto been paid to this interesting and useful branch of science, so indispensable to the prosperity as well as renown of the nation.

# SHIP-BUILDING.

## *Introductory Observations.*

**Introduction.**

**Aphorism of Sir Walter Raleigh.**

THAT profound thinker, Sir Walter Raleigh, has left this aphorism on record, "Whosoever commands the sea commands the trade; whosoever commands the trade of the world commands the riches of the world, and consequently the world itself." The time has passed by in which the command of the seas either can or ought to be maintained according to the spirit in which Sir Walter Raleigh framed this aphorism. Still the principle it is intended to enforce is as essential to the wellbeing of England now as it was then. We rejoice at the liberality of international communication, and of the political relations which distinguish the present age. We do more; we fervently hope that the same spirit may increase, even until all national distinctions and national divisions shall vanish before it. Yet we cannot but remember that it is with nations as with individuals. Interests may clash, quarrels may arise, and the friendships and the kindly feelings of to-day may be succeeded by the dissensions and the feuds of to-morrow; and therefore, even in the midst of a peace unexampled for its heartiness, and for the good faith which apparently pervades the councils of the nations of Europe, we cannot with wisdom neglect those means of defence which have hitherto preserved our land inviolate.

**Continental naval policy.**

The aphorism of Sir Walter Raleigh is of general application; but to an insular power, and which can only be reckoned of secondary rank in the scale of nations, in as far as size and population only are involved, naval pre-eminence is essential to its independence. An eminent statesman has lately most forcibly urged upon the continental nations of Europe this all-important fact, that the command of the seas, when vested in an insular power, gives her despotic authority over the nations of the earth, because she is herself invulnerable. He proceeds from this position to the conclusion, that the interest of Europe renders it imperative, that since the sceptre of the seas is at present held by an insular power, it should be wrested from her grasp, and bestowed on another, which, by being continental, must be vulnerable on her land frontier, and cannot therefore be despotic in her naval rule. Thus far does the continental writer pursue the argument, because thus far only are the interests of continental nations concerned; but for us there is yet another induction to be made; it is this: The same cause which invests an insular power with universal dominion as long as she can maintain the sovereignty of the seas, must divest her of all power when that sovereignty is lost; she falls at once from her high pre-eminence; first on the list of nations, to rank among the secondary powers; for the sea, her impregnable fortress in the one case, becomes a barrier to her enterprise in the other. It would be no difficult task to prove, from the history of Europe, that the influence of England among the nations has increased or diminished in proportion as her navy has been fostered or neglected.

It is strange, that with such a tremendous stake at issue as national independence, it should be possible to write, and to write with truth, that there have been periods in our history, during which the navy and the naval resources of this country have been suffered to decline. The naval sceptre has more than once trembled in our grasp: we trust the time is far distant in which we may again wield it in anger; but should that time ever arrive, the struggle must be desperate, because the powers of Europe have been taught that our naval pre-eminence places their destinies in our hands.

In connection with the occasional neglect of her naval resources, is another strange anomaly, namely, that England has less than any other maritime power encouraged the application of the exact sciences to naval architecture. She has not to this day one original truly scientific treatise on the subject in her language; and, passing by some few papers and tracts of modern times, she can only cite the writings of uneducated and unlearned men, as Mungo Murray, Hutchinson, and Stalkart, against those of such names as the Bernoullis, Euler, Chapman, Don Juan, Bouguer, Clairbois, Romme, and a host of others. The establishment of a school for naval architecture at Portsmouth has been directly and indirectly the means of diffusing much knowledge on this important subject, and the result has been a very considerable improvement in our ships of war, so that latterly they may perhaps fairly claim equality with those of other nations. It is perhaps principally in her merchant-shipping that England now suffers from this neglect of science.

**Introduction.**

**England has few or no scientific treatises on naval architecture.**

It is a recognised principle that demand creates supply, and therefore we may presume that in England there has been no demand, such as would encourage men of science to furnish forth the supply. It is not irrelevant to the subject of this article to trace out the causes which have operated to this effect; they must be made known to be removed; and it is in vain to urge improvement if there be any insuperable bar to its progress in operation. And again, it cannot be irrelevant, in an article on a national subject, and in a national work, to pursue the inquiry to its end, the more so as we believe the task will lead us to the conclusion, that, however harmless hitherto this state of apathy to improvement may have been, the time has now arrived when its continuance will be dangerous to our naval pre-eminence; for through it, to quote again from Sir Walter Raleigh, we may lose "the command of the trade of the world, the command of the riches of the world, and consequently of the world itself."

**English predilection for the sea of early origin.**

The predilection for the sea, and for a seafaring life, which is proverbially general throughout the population of England, may most probably be traced to an early period in our history, when, after the Norman conquest, for a long period of years, both shores of the narrow seas were under one rule, and the nobles of the land had possessions on either side of the Channel. This, and the constant intercourse kept up between England and her armies during the long subsequent wars, must have trained a hardy race of seamen, and have made passages by sea familiar to the entire population. The impression once given, the facilities afforded for maritime adventure, by the great comparative extent of our coast, and its numberless harbours, were quite sufficient to maintain it. Our insular situation will not alone account for our love of naval enterprise; otherwise a similar predisposition would be general with the inhabitants of islands, whereas we find a most remarkable instance to the contrary in Ireland, a country possessed of even more maritime advantages than England; with a more indented, and therefore a more favourable coast, with proportionally larger rivers, and with many lakes of great magnitude in the interior. This predilection of our population for the sea has hitherto enabled us most triumphantly to maintain our naval pre eminence, even against the known and acknowledged advantages of superior ships; for it is universally admitted that the naval powers of the Continent have, throughout their struggles with us, been possessed of superior classes of vessels, in many respects, to those which we have employed against them.

It is a question for serious consideration, whether we are sure, throughout the future, to be able to contend with equal success should we labour under similar disadvantages; or whether there are causes now in operation which may render a favourable result questionable?

**State of the theory of ships.**

In pursuing our inquiry into the present state of the theory of ships, and particularly as it is applied to our mercantile navy, we shall arrive at an answer to this question. It certainly does not necessarily follow, that because our vessels of war have been inferior to those of other nations, our merchant-shipping should be in a similar position with respect to their mercantile navies.

**Loss of merchant-ships from defective construction.**

The merchant princes of England, with their boundless wealth, proverbial generosity, and persevering enterprise, might surely have attracted the attention of men of science to the improvement of their argosies. That they have not done so is indisputable: the startling fact, that one ship and a half is the average daily loss registered on the books at Lloyd's, appears as a sad corroboration of the acknowledged truth, that the mercantile navy of England is the least speedy and the most unsafe that belongs to a civilized nation. Several causes have combined to produce this result, and to check any improvement in our merchant-ships. These it will be our object to explain.

**Reasons for their inferiority.**

During the late long war, when our fleets swept the commerce of the other nations from the seas, almost the whole traffic of the world was in our hands, and the carrying trade was shared only by the Americans, their neutrality obtaining for them the same advantages that we commanded by our power; but at the peace the seas were again free to the ships of all nations, and that which had been for a long series of years almost a monopoly, was thrown open to competition. It might naturally be inferred that this would operate injuriously to us; yet the question cannot but arise, why, with all the advantages of possession of the ground, of connection, and of stock, we have been, and still continue to be, supplanted by other maritime nations? We have not only lost much of the carrying trade for foreign merchants, but even English merchants find it for their interest, as individuals, to employ a great proportion of foreign shipping, to such an extent indeed, that nearly one half of the commerce on our western coast is carried on in American vessels. It may be urged against these statements, that the statistics of our mercantile navy show an increase in its numerical strength. This may be admitted, and the force of the argument remain the same; for it is not founded on its positive increase or decrease, but on its relative increase compared with that of the mercantile navies of other nations.

**Diminished demand for our shipping.**

That there should have been a diminution in the demand for our shipping at the conclusion of the war, is a necessary consequence of the many causes of the employment of ships which belong only to a state of war; besides which, as in time of peace the delays occasioned by waiting for convoy are avoided, the time expended in the voyages is shorter, and therefore a less number of ships is required to perform the same quantity of work. We have, however, suffered more than the proportion due to these considerations, which, it should be remembered, must also, in a lesser degree, have operated to check the progress of the American mercantile navy; however, it is this navy which is principally supplanting ours. We cannot evade the conclusion, that the reason for this must be found in the inefficiency and inadequacy of the ships themselves, and that the absence of all improvement in our mercantile navy has placed it in this disadvantageous position.

**Caused by inadequacy of our ships.**

**Ships sailing in convoy.**

During the war, almost the only colonial supplies which could reach the continental powers were those plundered by their privateers from the English merchant. The only safety to the English merchant-ship was in sailing in large convoys, in which the velocity of the whole fleet was necessarily regulated by that of the worst sailer. It was therefore of far more importance to the merchant who had few opportunities for adventure, to choose those ships which would carry a larger quantity than those which were possessed of a quality, velocity, of which they could not avail themselves. This operated as an effectual bar to all improvement in the forms of our mercantile shipping, for it caused the absurdities of the late law for tonnage to remain unnoticed for a series of years; and when at length their injurious tendency was perceived, it was not until they had become so completely identified in men's minds with ships themselves, that years more were suffered to elapse before it was clearly made manifest, that the cause of the inferiority of the shipping was the absurdity of the law. Years more must yet elapse before the mercantile navy of Britain can recover from the state to which these laws have reduced it.

**Tonnage laws.**

**Their injurious operation.**

**American ships sailed singly.**

While English merchant-ships were restricted to sailing in convoys, the neutrality of the Americans enabled their vessels to sail singly, and consequently it became immediately desirable to attain the greatest velocity which was consistent with a due portion of the other requisite qualities for a merchant-ship; there was therefore virtually a premium on improvement. Thus the peace found America in possession of an immense commercial navy, which, on an average, could perform its passages in one third less time than our own; and although this is necessarily attained by some sacrifice of capacity, the result has shown the sacrifice to have been judicious. The peace also found America in possession of ship-builders who had made the improvement of the qualities of ships their study. She therefore was not only in possession of a better mercantile navy, with which to compete with us, but she had also the vantage-ground of superior knowledge, and a far more extended experience, from which to start for the future competition. What wonder, then, that we have failed in the contest? The wonder should rather be, that we are not wholly driven from the field. Similar injurious causes operated against the English shipping in comparison with that of several of the maritime powers. Convoy was no safety to their ships of traffic, since their ships of war found no safety for themselves. The only chance for escaping our cruisers lay in sailing singly, as less likely to attract observation, and in trusting to their velocity if observed; besides which, the northern nations of Europe have long been possessed of a very superior class of mercantile shipping, the result partly of the advanced state of the knowledge of the science of naval architecture among them, and partly also of this custom of sailing singly on long voyages, even amidst all the dangers of war. It cannot be a matter of astonishment, therefore, that when the seas were once more open to ships of all nations, the foreign merchants, whom absence of commerce had impoverished, should choose those which would the soonest allow of a return of capital, and at the same time diminish the risk of its loss; for it must be remembered, that the safety of a ship is not only dependent on her powers as a sea-boat, but is in inverse proportion to the time she is exposed to the dangers of the seas. Again, if the foreign merchant thus preferred the foreign ship to the British, surely that competition, which is the very spirit of commercial enterprise, must of necessity have impelled the British merchant to pursue the same course; for it could not be a matter of indifference to him whether his goods should be the first in the market, or should arrive when that market was glutted.

**Convoy no safety to foreign ships.**

**Present tonnage law.**

The present modification of the tonnage laws is comparatively harmless, but the leaven of the old law remains. England possesses upwards of two millions and a half of tonnage in inferior shipping; and the merchant-builders of Britain, reared under the baneful influence of that law, are, with a few honourable exceptions, unequal to the task of competition with the more educated and more practised foreigner. The theory of ships is, even by those who are the most instructed in its principles, yet considered in its infancy; it

Difficulty of the study of the theory of ships.

can only be matured by a free and impartial encouragement of the application of the exact sciences to the improvement of naval architecture, and by the total abolition of all laws which can, directly or indirectly, limit the aspirings of the merchant-builders of England in their competition with foreigners. The writer of this article believes that England scarcely ever committed a greater error than when she first determined the existence of a law for levying duties according to tonnage.

Error in having restrictions on ship-building.

We may here advert to a most striking example of the effects of the removal of this check, in the matchless excellence of the yachts of England, and may therefore not unfairly presume, that the same skill which has already exalted one class of vessels beyond competition, might, under similar circumstances, attain the same comparative excellence for another, and that our merchant-ships may yet become as unrivalled as are our yachts. Be the law of tonnage founded on weight, on bulk, or on dimensions, in each and every case it operates as a check to the most important manufacture of the country. There is evidently nothing so essential to England as that she should possess a large maritime population; and this can only be insured by the preponderance of her mercantile navy, which, again, must in future be completely dependent on the qualities of the ships that compose it.

Ships to train seamen the paramount want of England.

It is obvious, that while the effects of a long, and solid, and, we believe, hearty peace, amongst the civilized nations of the world, are to increase the wealth of all other nations as well as our own, and with their wealth to increase their shipping, it becomes a serious national duty on the part of our rulers to frame such laws as may insure to us the vantage-ground we possessed when peace enabled all alike to start in the race of improvement. That we may have free exercise for our skill, capital, and enterprise, we must not be cramped by absurd laws as to the tonnage and sailing regulations of our ships. These impediments should evidently be removed, in order to place us at least upon equal terms with our competitors.

We do not pretend to arrogate to ourselves that command of the seas which was intended by Sir Walter Raleigh. The days when fleets were bound to lower topsails at the bidding of a single pennant have, happily for the wellbeing of mankind, long passed away. But we do say that the end and object of all British policy should be to insure such preponderance on the seas, that if, amidst the changes which we almost daily see occurring, and which make the possible advent of war no speculative imagining, one should arise to plunge Europe again into strife, England may not be found wanting in practised seamen. This, we believe, can only be assured by her possessing a mercantile navy, composed of ships the good qualities of which will insure for them a large proportionate share of the carrying trade of the world. In short, we believe, that, to insure for our military navy, in times of war, successes triumphant as heretofore over every sea, it is essential that our mercantile navy should, in these times of peace, crowd every port.

It is in order to advance this cause that we shall endeavour to set in a clear point of view the several difficulties which occur in the study of naval architecture; and we feel no doubt whatever, that if the principles of construction which we shall endeavour to explain be duly attended to, and the study followed up in earnest, the results will prove their correctness, and that the mercantile navy of England will become as unrivalled in its excellencies as are almost all the other productions of the skill, talent, and enterprise of this favoured land.

### *Rise and Progress of Naval Architecture among the Nations of Antiquity.*

Charnock's chronological divisions.

In tracing the progress of naval architecture among the nations of antiquity, in order to connect it with its advance in more modern times, we shall cite the chronological divisions adopted by that indefatigable investigator Charnock, in his valuable History of Marine Architecture, because they present a very succinct idea of the probable rise, progress, decline, and revival of the art, and therefore offer a valuable guide for investigation. It would not be consistent with the purpose of this article to enter into the detail that would be necessary to ascertain the state of naval architecture during the periods embraced in each of the sections he has assigned to this subject. We shall confine ourselves to the statement of some few facts, collected from various authors, in illustration of the probable size and nature of the shipping of the ancient world. We shall also endeavour to trace what little is known of the rude vessels which, during the darkness of the middle ages, bore the marauders of the northern nations on their predatory excursions; in which they carried desolation and misery throughout the coasts of Europe, and, while they rooted out the last relics of ancient civilization, laid the foundations of empires which were destined, in their turn, to civilize the world. With Charnock's sixth section, inclusive perhaps of some few years at the close of his fifth, the naval history of Britain commences; and during the period embraced between that date and the present time we must gradually become more diffuse in our detail.

Charnock divides maritime history into seven sections. The first comprehends the time previous to the foundation of Rome, until which, he says, all history is founded on surmise. The second section comprises a period somewhat less obscure, in which the collateral testimony of various authors may be examined and compared; and therefore there certainly appears less difficulty in ascertaining facts. It extends from the foundation of Rome to the destruction of her rival Carthage. The termination of the third is at the conversion of the republic into an empire, an era when the want of naval enemies to contend with rendered the maintenance of a fleet, as connected with the prosperity and safety of the state, a consideration not only of secondary, but immaterial consequence. The death of Charlemagne ends the fourth epoch. The fifth extends from this period to the discovery of the mariner's compass. The sixth ends with the discovery of cannon; and their adaptation to naval warfare commences the seventh epoch.

Ancient shipping principally propelled by oars.

It will avoid much useless repetition if we premise our investigations on the state of ship-building among the nations of antiquity, by the observation that their fleets, whether for war or for commerce, appear to have consisted almost entirely of vessels whose principal mode of propulsion was by the use of oars. It would be foreign to the object of the present article to enter into the useless and perplexing, though most enticing question, as to how those oars were applied in the trireme, quadrireme, and quinquireme, nay, on the authority of Plutarch, even to the extent of fifty distinct banks of oars. It is possible to conceive many methods in which the benches of the biremes, and even of the triremes, may have been disposed, which would enable the oars to be plied with ease and advantage. But the vast combination implied by the fifty banks of the galley of Ptolemy Philopater has as yet received no solution, unless it may be that suggested by Mr Holwell in his Essay on the War Galleys of the Ancients, which we shall therefore, in the absence of all certain data, adopt. He imagines that the banks of oars must have been arranged obliquely up the sides of the vessel, as many oars in each bank as would admit of the highest being rowed with facility; then each additional bank would only require additional length in the vessel. Thus the galley of Ptolemy Philadelphus might have had forty, and that of Ptolemy Philopater fifty, of these oblique ascents of oars, and yet need not necessarily have been higher out of the water than the ordinary quinquireme. It should be stated, that the triremes seem to have been the limit of practical utility in the disposition of the oars, as they appear to have been most usually adopted for the purposes of war.

**Trojan war.**

In tracing the records of the sizes of vessels, we find, on the authority of Thucydides, that the Grecian flotilla, at the siege of Troy, about 1184 years B. C., consisted of 1200 vessels, the largest of which contained not more than 120, the least fifty people. He also expressly says that they were without decks. These were therefore mere open rowboats or canoes.

**First naval battle.**

A great improvement on these must have been made in the fleets of the Corcyrians and Corinthians, between whom took place the first naval battle on record, and which occurred about 650 years before Christ; because at that time it appears the arrangement of the oars in banks had been introduced.

**Sails evidently little used.**

We may perhaps infer, from a statement made by Thucydides, that these vessels were not adapted for carrying any large portion of sails, as they evidently had little if any ballast. He says (book i. chap. 50), "The Corinthians, when their enemies fled, staid not to fasten the hulls of the galleys they had sunk unto their own galleys, that so they might tow them after, but made after the men, rowing up and down to kill rather than to take alive." The vessels spoken of as sunk were evidently merely stove in and water-logged.

**Inventors of the triremes and quinquiremes.**

Herodotus, Thucydides, and Diodorus agree that Aminocles, the "shipwright of Corinth," was the inventor of the trireme, about forty years previous to this battle. The invention of the quinquireme is generally attributed to the Carthaginians.

**Salamis.**

**Fleet of Mardonius.**

At the battle of Salamis, 480 years B. C., on the authority of Plutarch, the largest Grecian vessels carried only eighteen soldiers, exclusive of the rowers, and those employed in manœuvring the vessels. In the fleet of Mardonius, crowded as it must have been by a force collected for the purpose of invasion, we find that, on a comparison of the number of ships lost by tempest and the number of men drowned, the average is only sixty-six men to each vessel. This fleet consisted of 1200 galleys, and 2000 hulks (ὁλκάδες) of the "round manner of building."

**Vessels half decked.**

**Decks introduced by Cimon.**

The whole of the Grecian vessels appear to have been only half-decked; the soldiers were stationed on platforms at each extremity, the middle or waist being left open for the rowers. Cimon, the celebrated Athenian commander, was apparently the first to join these two platforms with an intermediate flat, and thus to form a perfect deck, for the purpose of opposing a stronger armed force to the Persians. This innovation took place preparatory to the battle of Eurymedon, B. C. 470. These decks were hatches to be removed at pleasure. The quinquiremes appear afterwards to have been always thus fitted, the quadriremes and biremes only occasionally; and all below these in size were open boats.

**Ships of slight build.**

From the rapid preparation of armaments of most imposing force, in as far as numbers of shipping are concerned, and also from the fact of the ease with which the vessels were transported by land, we must infer that they were of but small dimensions, and of very fragile construction; and though occasionally we find that fabrics of large size were constructed, it was evidently, from the gorgeous descriptions which remain of them, more out of ostentation than from any anticipation of their utility.

**Fleet of Nearchus.**

The vessels composing the fleet of Alexander the Great in his Indian expedition, and in which Nearchus performed his celebrated voyage, were row-galleys of such moderate dimensions that, in the course of the voyage, they were frequently hauled on shore; and although we find, by collating the number of vessels and the number of men composing the expedition, that there could not have been more than fifty or sixty men on board each vessel, their accommodations were so poor that the journal takes notice of the inconvenience experienced by the crews from being obliged to remain for two consecutive nights on board. Purchas gives the detail of this voyage of Nearchus, on the authority of Arianus, lib. viii.

**Carthaginians.**

**Voyage of Hanno.**

To pass to the Carthaginians, a people of great commercial enterprise and importance, and who inherited their nautical knowledge from their progenitors the Phœnicians, of whose commercial wealth history, both sacred and profane, gives repeated evidence: Ezekiel (chap. xxvii.) says of Tyre, It is situated at the entry of the sea, is a merchant for many isles; its ship-boards are of fir-trees of Seoir, their masts of cedars, their oars of oak of Bashan, their benches of ivory, their sails of fine embroidered linen. We find that the Carthaginians must at a very early period of their history have possessed vessels of considerable magnitude; for in the journal of the much though unjustly disputed voyage of Hanno, which Clark, in his History of Maritime Discovery, places at 350 B. C., but which by some historians is said to have taken place as early as 1000 B. C., sixty ships afforded accommodation for 30,000 souls, including women and children, and this, too, with all the stores and requisites for colonization, which was the main purport of the enterprise. The little we know of the Carthaginians, we know through their implacable foes the Romans; and as the Roman fleets were built after a Carthaginian model, we may pass on to investigate the few certain particulars we can collect of the Roman shipping; though, in doing so, we must not assume that we are in possession of the extent of the state of naval science among the Carthaginians. All that the Romans adopted from them was their war-galley. Their commerce, and consequently their commercial vessels, were alike despised by this predatory state, which then lived almost solely by the sword.

**Roman shipping.**

Charnock, on the authority of Meibomius, has given the following as the dimensions of the Roman trireme and quadrireme. The triremes were 105 feet long and eleven feet broad. The quadriremes were 125feet long and thirteen feet broad. The triremes, after the time of Julius Cæsar, were ninety feet long and ten feet broad. These dimensions have a much greater comparative length to breadth than the proportions adopted for the Neapolitan and Maltese galleys of more modern times. In them the length seldom exceeded seven breadths. According to Vossius, who is also one of the most voluminous writers on the subject of the shipping of the ancients, these Neapolitan galleys were capable of performing voyages by the oar of sixty leagues in twenty-four hours; and the distance from Naples to Palermo has been performed in seventeen hours.

**Cæsar's account of the size of ships.**

Cæsar himself gives us a good criterion of the size of the Roman vessels employed by him in the invasion of Britain; for he says that they were so large that they could not approach near enough to the shore for the soldiers to disembark, but that they were obliged, encumbered as they were with their arms, to jump into the water, which was breast high; and that at last the galleys were ordered in between these larger vessels and the shore, to protect the disembarkation.

**First Roman fleet.**

When we consider the dimensions above quoted for the Roman navy, it does not appear that there is necessarily much exaggeration in the accounts given of the wonderful exertions made by that people to prepare their first maritime force. Sixty days after the axe was laid to the root of the tree, 160 galleys according to some accounts, 100 quinquiremes and twenty biremes according to others, rode at anchor in the sea; the quinquiremes each manned by 300 rowers and 200 soldiers. Polybius states the Roman fleet at the time of the first Punic war to have consisted of 330 ships, each containing 300 rowers and 120 soldiers. If we compare the small number of vessels which the might of Rome put forth at this time, when her very existence depended upon the success of her naval exertions, and then contemplate the enormous numerical force of the fleets of the petty Grecian states, we may form a very correct judgment of the necessarily comparative insignificance of the vessels which composed these more early navies.

**Classes of Roman Shipping.**

The Roman ships were divided into three classes: the *naves longæ*, or ships of war; the *naves onerariæ*, or ships of burthen; and the *naves liburnæ*, which were ships built expressly for great velocity, and may be supposed to have been used as despatch-boats, and for making passages with important personages. There is repeated evidence to prove that these vessels were invariably built of pine, cedar, or other light woods, excepting about the bows, which were of oak, strongly clamped and strengthened with iron or brass, in order to withstand the shock of opposing vessels; the tactics being comprised in the attempt to sink or damage the enemy's vessel, by violently propelling this armed bow against the weaker broadside of the enemy, or else endeavouring to break and cripple the oars. Oak was first applied to ship-building by the Veneti. This we have on the testimony of Cæsar in his treatise *De Bello Gallico*, lib. iii. cap. 13. Copper or brass was introduced for fastenings, in consequence of the quick corrosion of the iron, about the time of Nero. This is stated on the authority of Vegetius, and also of Athenæus; and Pliny mentions that flax was used for the purpose of caulking the seams of the plank.

**Oak first used in ship-building.**

**Copper.**

**Caulking.**

**Exhumation of a Roman vessel.**

The following quotation is from Locke's History of Navigation: "Sheathing of ships is a thing in appearance so absolutely new, that scarce any will doubt to assert it altogether a modern invention; yet how vain this notion is, will soon appear. Leo Baptisti Alberti, in his book of Architecture (lib. v. cap. 12), has these words: But Trajan's ship weighed out of the lake of Riccia at this time, while I was compiling this work, where it had lain sunk and neglected for above thirteen hundred years; I observed that the pine and cypress of it had lasted most remarkably. On the outside it was built with double planks, daubed over with Greek pitch, caulked with linen rags; and over all a sheet of lead fastened on with little copper nails. Raphael Volaterranus, in his Geography, says this ship was weighed by the order of Cardinal Prospero Colonna. Here we have caulking and sheathing together, above sixteen hundred years ago; for I suppose no man can doubt that the sheet of lead nailed over the outside with copper nails was sheathing, and that in great perfection, the copper nails being used rather than iron, which, when once rusted in the water, with the working of the ship, soon lose their hold and drop out."

Slight as this sketch may appear of the navies of antiquity, it embraces an outline of almost all that has descended to our times. No portion of ancient history is so imperfect as that which relates to the shipping, and in none necessarily has the historian derived less aid from remains. Even the monumental records here fail him, as the prow alone is sculptured on them.

### *Progress of Naval Architecture from the Downfall of Rome to the present Time.*

**Middle ages.**

During the many centuries of utter stagnation in all improvement which succeeded the downfall of ancient civilization, it would appear vain to seek for records of the progress in naval architecture. "These were times," says Rymer, in the dedication of the third volume of the Fœdera, "of great struggle and disorder, all Europe over, and the darkest period of times." Although it may be useless to search for records of the improvement of the means of navigation during these ages, when thought appears to have been banished from the earth, and action to have been the only object of man's life, we may undoubtedly expect that, in the countries bordering on the seas, the spirit of naval enterprise would be peculiarly fostered, as congenial to man's habits, or essential to his preservation, during a period of universal aggression, confusion, and migration. The northern regions of the earth, regions which the civilization of the south had deemed uncongenial to man and unfit for his habitation, appear to have teemed, in all their wild and far-spreading districts, with a hardy and an adventurous population, horde after horde of whom poured down from the north-east in irresistible might, and spread desolation and misery throughout Southern and Western Europe; while from the north-west the same wide-spreading desolation swept away all trace of the incipient civilization of Britain and of Gaul. Every sea was ploughed by the fragile barks of the Scandinavian adventurers, and every shore was devastated by their incursions. Denmark, Norway, and Sweden sent their hardy sons to the coasts of the German Ocean, the Channel, the Bay of Biscay, and even to the Mediterranean on the west; while the barbarians of the Sclavonian nations poured down through the Danube and the Borysthenes on the east of Europe, the population of which, rendered feeble by the divisions and dissensions attendant upon the breaking up of the gigantic power of Rome, and enervated by the Sybarite civilization of the latter days of that empire, perished beneath the arms or bent to the yoke of the hardy progeny of the north. The Saracens wrested from the descendants of the Cæsars the remnant which the Goth and Hun had spared; and Europe became repeopled throughout its limits with a young, a vigorous, and an enterprising population, while the maritime provinces had generally been the spoil of tribes inured to the dangers and delighting in the excitement of maritime adventure.

**Northern nations.**

**Their enterprise.**

We cannot but be astonished at the indomitable spirit of enterprise which characterized these rude times. But that, perhaps, which is the most extraordinary feature of the daring that distinguished this period, is to be traced by the results of its naval expeditions, which could not be believed, had they not been established on the most unquestionable evidence; and the whole history of the middle ages, with their revolutions, may be cited in corroboration of them. Still they had such important influence on the state of Western Europe, that, judging of causes by their effects, there must ever remain a doubt of our being in possession of correct information as to the means by which the results we speak of were accomplished. It is not difficult to suppose adventurous men trusting themselves to the mercies of the winds and the waves, and leaving the sterile north to plunder and colonize more favoured climates, of the existence of which their traditions might inform them. But this is not all: there is ample evidence to prove a recurrence of such enterprising voyages, their successful achievement, and the safe return of the adventurers, not only to Norway and the main land, but to Iceland; a remote spot, which might be left, but certainly could not be again repeatedly attained without more knowledge than we are willing to concede to so remote a period.

**Their comparative difficulties.**

The navigator of the present day, accustomed to rely on the almost infallible aid of the compass, the chronometer, and the sextant, would pause ere he dared to commit himself to the boundless expanse of ocean, with no more sure pilotage over its trackless waters than he might chance to find from the appearance of the sun or stars and the flight of birds. And yet we have no record that these Scandinavian sea-kings knew of more certain guides than the sun by day, the stars by night, and such further aid as perchance might be wrested to their purpose, from the varied phenomena of nature; phenomena which may now be unobserved, because not needed.

**Voyage of Floke.**

We read in Purchas's Pilgrims the following account of the voyage of Floke, a Norwegian pirate, made in the early part of the tenth century, from Shetland to Iceland; which he gives on the authority of Arngrim Jonas, an Icelandic historian. “There was yet no use of the marinrs compasse, wherefore Floco leaving Hietlandia, tooke certayne ravens unto him; and when hee thought hee had sayled a great way, he sent forth one raven, which flying aloft, went backe againe to Hietlandia, which she saw behind. Whereupon Floco perceiving that he was yet neerer to Heitlandia then other countryes, and therefore couragiously going forward, he sent forth another raven, which, because she could see no land, neither before nor behind, light unto the ship again. But, lastly, the third raven was sent forth by Floco, and having for the most part performed his voyage, through the sharpnesse of her quicke sight attayned the land, she speedily flew thither, whose direction Floco following, beheld first the eastern side of the iland.”

**Saxon vessels.**

The vessels of the Saxon marauders are described by Charnock in the following terms: “The keel of their large flat-bottomed boats was framed of light timber, but the sides and upper works consisted only of wicker, with a covering of strong hides. The Saxon boats drew so little water, that they could easily proceed four score or an hundred miles up the great rivers; the weight was so inconsiderable, that they were transported on waggons from one river to another; and the pirates who had entered the mouth of the Seine or the Rhine might descend with the rapid stream of the Rhone into the Mediterranean.”

This description of the skin-covered boats of the northern seas is founded on testimony which cannot be disputed. And, if they were used by the Northmen on their longer voyages, it was probably when they purposed incursions into the interior of the countries they were about to devastate; but that they must have had another and a far superior description of vessel, there can be no reason to doubt.

**Royal Society of Northern Antiquarians.**

**Gaulish Veneti.**

The investigations of the Royal Society of Northern Antiquarians at Copenhagen have thrown considerable light on the subject of this early navigation, and of the discoveries of the Scandinavians in the west; and we can no longer suppose that it was in these coracles that frequent voyages were made to Newfoundland, and colonies established there, which it appears proved that there were even as early as the tenth century. But to recur to evidence which is familiar to us. We have the description given by Cæsar of the ships of the Gaulish Veneti. “Their bottoms were somewhat flatter than ours, their prows were very high and erect, as likewise their sterns, to bear the hugeness of the billows and the violence of the tempests. The body of the vessel was entirely of oak. The benches of the rowers were made of strong beams about a foot in breadth, and fastened with iron nails an inch thick. Instead of cables, they secured their anchors with chains of iron; and made use of skins and a sort of thin pliant leather, by way of sails, probably because they imagined that canvass sails were not so proper to bear the violence of tempests, the rage and fury of the winds, and to govern ships of that bulk and burthen. ……Neither could our ships injure them with their beaks, so great was their strength and firmness, nor could we easily throw our darts, because of their height above us, which also was the reason that we found it extremely difficult to grapple the enemy and bring them to close fight.” And again, speaking of the manner in which these ships were eventually taken possession of: “They,” the Romans, “had provided themselves with long poles, armed with long scythes; with these they laid hold of the enemies' tackle, and drawing off the galley by the extreme force of oars, cut asunder the ropes that fastened the sailyards to the masts; these giving way, the sailyards came down, insomuch that as all the hopes and expectations of the Gauls depended entirely on their sails and rigging, by depriving them of this resource we at the same time rendered their vessels wholly unserviceable.”

The account proceeds to state, that many attempted to escape from this unforeseen means of aggression; but that the wind falling, and a perfect calm coming on, they were obliged to remain inactive on the water, and were taken possession of, one after the other, by the simultaneous attack of several Roman galleys. It would appear from this that they were vessels only intended for sailing, and that since oars were used, from the mention made of seats for the rowers, they could have been as very partial accessories to the sails, or probably even only for steering. Another fact is mentioned by Cæsar, that the Veneti sailed from their port to meet the Roman fleet, and several of the vessels escaped to their port from the fleet. This, though not conclusive of the fact of sailing on a wind, is worthy of notice.

**Hengist and Horsa.**

It is probable that it was ships such as these which brought Hengist and Horsa to England about the middle of the fifth century, since it is recorded that their force, which consisted of 1500 men, found accommodation in only three vessels. It is hardly to be imagined that the coracles or skin-boats of the northern nations were ever of sufficient dimensions to accommodate a force of 500 men, with arms and means of active aggression.

**Danish invasions.**

In the course of little more than a century from the first invasion of Hengist and Horsa, England became quietly subject to Saxon rule; and the prosperity incidental to a state of peace made her again a fit object of prey to new hordes of northern pirates, the Danes. But it is useless to dwell long on these times of historical doubt and inaccuracy. In the words of Milton, “These bickerings to record, what more worth is it than to chronicle the wars of kites or crows, flocking and fighting in the air.”

**Dawn of civilization.**

At length order once more asserted her right to control men's actions, and out of order the arts and wants of civilization began again to dawn in the newly-formed states which had arisen from the wreck of the empires of antiquity. Man then saw that peace ministered to his comfort, and he turned his thoughts to commerce rather than to the sword, as a means of gratifying his newly-acquired cravings. Thus a long period did not elapse before those seas, which had for centuries been tracked only by the bark of the lawless marauder, bore on their surface the well-freighted craft of the peaceful and industrious merchant.

**Rise of Venice.**

The earlier irruptions of the northern barbarians into Italy had desolated the Roman province of Venetia, and driven a remnant of its inhabitants to the refuge afforded by the small marshy islands at the extremity of the Adriatic. There they are described by Cassiodorus, who assimilates them to water-fowl, as subsisting on fish, and steeped in poverty, their only manufacture and their only commerce being salt. From such humble beginnings arose the state destined to connect the old world with the new, and to lead the van of modern commercial and maritime enterprise. The mercantile prosperity of Venice diffused its influence throughout the shores of the Mediterranean, which thus became once again the nursery of civilization. For many centuries Venice was the great school for the arts connected with navigation, and her shipwrights and seamen were long the most instructed in Europe. While the northern seas were navigated by the Scandinavian sea-kings, in their rude and frail boats, in quest of plunder or of a home, ships floated on the waters of the Mediterranean bearing the banner of St Mark, which, it is said, were, even as early as the tenth century, of the burthen of 1200 up to 2000 tons. The vessels, however, generally adopted by the Mediterranean states, were either copies or modifications of the ancient galley.

**Mediterranean galley.**

It is a fact worth notice, that while the continuation of the use of this species of vessel in the comparatively tranquil waters of the Mediterranean fostered the arts of commerce and navigation, its introduction into the northern seas, to which it was ill adapted, appears to have checked, in a most remarkable degree, the maritime enterprise which had hitherto so characterized the population of their coasts. It is even probable that the barrier thus opposed to commerce entailed on the states of Northern and Western Europe centuries of comparative barbarism. Yet this was effected for a wise purpose, by one of the greatest ornaments of the middle ages, Alfred the Great.

Alfred.

Alfred was the first ruler of England who clearly understood that the policy of Britain was rather to prevent than to resist invasion; and the by-gone history of his country told him plainly that its military strength was not only insufficient to awe invaders from its shores, but that all the military resources at his command were inadequate to preserve the liberties of his people. He therefore turned the energies of his mighty mind to the task of creating a naval force, which should be more powerful than that of his untiring persecutors the Danes. In this we find that he succeeded; and at length, under the protection of the fleets which his genius had created, he was enabled to establish that frame-work of internal policy and government, from the wisdom of which England has even to this day benefited. It is historically certain that Alfred himself superintended the formation of his fleet, and that he gave the design of vessels to be superior to those of the Danes.

His ships.

We find that these vessels were galleys, generally rowed with forty oars, some even with sixty, on each side; and that they were twice as long, deeper, nimbler, and less "wavy" or rolling, than the ships of the Danes. The information on this subject is obtained by Selden, from a Saxon chronicle of the time of Alfred, which is in the Cottonian Library.

Reasons for their introduction.

It should be remembered, that when Alfred thus introduced the Mediterranean galley into these northern seas, his object was not so much to form a vessel adapted for the purpose of navigating those seas, as to obtain one which would afford space for a large force of fighting men. For this the galley was admirably qualified; and indeed it maintained its place as the appropriate ship for the purposes of war, until the invention of cannon rendered other arrangements necessary.

Their success.

The immunity which it insured from the attacks of the Danish marauders, caused its general adoption along the coasts hitherto open to their incursions, on all of which it thus superseded the sailing vessels that we have already described; and we shall find that voyages which, until its introduction, were boldly and successfully achieved, became of rare occurrence and of hazardous issue during the subsequent ages, until the galleys once again gave place to sailing vessels. It also gradually checked the enterprise of the Northmen, by the curb which it placed upon their successes.

Saxon rule.

It is not our purpose to give more than a slight sketch of the naval history of Britain through the line of her Saxon princes; for we can discover little data on which to found any speculation even, as to the progress of naval architecture during these ages. We know that the galley of the Mediterranean continued to be used for the defence of the coasts; and the policy of Alfred appears to have been well understood by many of his successors,—that England only enjoyed peace from invasion when her fleets were powerful enough to repel it from her shores. We are also led to suppose that the use of sailing vessels was not wholly abandoned; for in the reign of Athelstan, the third in descent from Alfred, as we read in Hackluyt, it was decreed, that "if a marchant so thrived, that he passed thrise over the wide seas of his owne craft, he was thenceforth a Thein's right worthie."

Mercantile shipping.

This establishes two rather interesting facts: one is, that at so early a period of our history there were merchants of importance enough to engage in such a traffic; and the other is, that from the richness of the reward held out to successful enterprise, we are enabled to estimate the difficulty of the task assigned. We may assume that these long voyages were made in ships more adapted for the purpose than galleys; in fact, in the vessels which the galleys had been intended to supersede. But the spirit of maritime enterprise had, as we have said, evidently received a check, since we see that one of the highest rewards in the power of the monarch to bestow was held out to the merchant, as an incitement to an adventure, which the vague hope of plunder would alone have been sufficient to induce that merchant's progenitors to attempt, and successfully perform. However, it is probable that at no time was the art of navigating vessels, which depended principally, although perhaps not wholly, upon their sails, lost in the northern seas. Gibbon says, that at the early crusades the vessels of the "Northmanni et Gothi" (the Norwegians and Danes) differed from those of the other powers, among all of whom the ships partook of the character of the Mediterranean galley. These northern crusaders are described by him as navigating "*navibus rotundis*, that is to say, ships infinitely shorter in proportion to their length than galleys." This was not later than the beginning of the twelfth century, and therefore not so far removed from the periods in question as to render the inference we wish to deduce from it erroneous, particularly when referring to times of such slow improvement as the middle ages.

Decline of naval enterprise.

Edgar.

The "mighty" fleets maintained by Edgar afford no information on the subject of this article, excepting that the facts connected with that monarch's annual circumnavigation of his territories prove them to have consisted of row-galleys. They must however have formed comparatively a "mighty" fleet; for, from a grant of land made by Edgar to Worcester cathedral, we find that he assumed to himself the title of "Supreme Lord and Governor of the Ocean lying round about Britain." That they were but of slight construction, we may infer from the low state of the navy so shortly after the death of Edgar as the reign of Ethelred, who, in order to re-establish it, instituted a regular tax for providing and maintaining a navy. It was enacted, according to Selden, that whoever possessed "310 hides of land, was charged with the building of one ship or galley; and owners of more or less hides, or part of one hide, were rated proportionately;" the hide being, according to the best authorities, as much ground as a man could turn up with one plough in a year. But this tax appears to have been inadequate to the purpose of providing a sufficient fleet, for all the exertions of Ethelred could not preserve Britain from again being ravaged by the Danes; and we find, that after the short reign of his son Edmund Ironsides, England was ruled by Danish monarchs. From the known talent of Canute, the first of these princes, and from the crowns of Denmark, Norway, and Britain being united in his person, we may presume that the naval affairs of England were not suffered to retrograde. We have indeed a record of their advance during this second Danish rule. We may also infer it from the present which was made by Earl Godwin to Hardicanute, the third Danish sovereign, of a galley, sumptuously gilt, and rowed by fourscore men, each of whom wore on his arm a bracelet of gold weighing sixteen ounces; not that the mere gorgeousness of the gift would prove any advance in the art of ship-building, but we may suppose, from its nature, that naval affairs found favour in the sight of this monarch. Of this we have also other historical evidence, as Hardicanute raised eleven thousand and forty-eight pounds, in the first two years of his reign, for the purpose of building thirty-two ships; and the taxes he levied for the support of his navy were so grievous that, Florentius says, scarcely any man was able to pay them.

Ethelred.

Canute.

Norman conquest.

The marine of England seems to have been maintained on a comparatively powerful footing up to the period of the Norman conquest; and from the naval resources at the command of Harold the Saxon, in comparison with the insignificance of the shipping which brought William and his

Normans across the channel, there can be no doubt that had Harold relied upon his naval strength, the conquest of England would never have been achieved. But, by some fatality, his fleet, which had been long stationed off the Isle of Wight, was dispersed, in consequence of a report that William had abandoned his enterprise.

**Fleet of William.**

The flotilla of William the Conqueror is variously stated; by some at 900, by others at 3000 vessels. In either number we have a scale to estimate their insignificance, as the invading force consisted of about 60,000 troops, which would give in the one case about sixty-six men to each vessel, in the other twenty men only. Plate CCCCXLV. figs. 1 and 2.

The conquest of England being completed, the shores on either side of the narrow seas between England and Normandy were under the same rule. William therefore claimed sovereignty over them, which right was maintained by his successors. There can be no doubt that the constant intercourse between the two portions of the empire, which continued throughout the Norman sway, and indeed for a period of upwards of three centuries, must have done much towards fostering a maritime spirit among the population of England, and accustoming it to consider that fame and fortune were the rewards of nautical adventure.

**Probable size of ships.**

We have but slight evidence as to the state of naval architecture during the early period subsequent to the conquest. There are a few facts scattered among the records of these times, which may enable us to draw some vague conclusions as to the probable size and nature of the vessels used. When Prince William, son to Henry I., was drowned, by the loss of the vessel in which he was crossing from France to England, it is recorded that three hundred souls perished with him. As of this number a large portion, historians say one hundred and forty, were men of rank, and as there were many ladies, since the prince was accompanied by his sister, the vessel must have been of considerable burthen. A similar event, namely, a shipwreck, that occurred during the reign of Henry II., by which nearly the same number of persons perished, tends to prove that such was about the extent of the accommodation afforded by the shipping of this period. Galleys still continued to be used for the purposes of war; but as commerce began to be extended, it became necessary to recur to the use of sails, and we find that they were therefore gradually recovering their importance, and superseding oars. Indeed it is difficult to conceive commerce to be profitably engaged in, attended with the immense expense of the crews necessary to propel the larger galleys. We should imagine that this had an important influence in the improvement of navigation and of naval architecture, for the commercial intercourse between the portions of the empire on either side of the channel must have been considerable. There is constant reference in the early chronicles to the great extent of the wine trade, and of the commerce in wool and woollen cloths.

**State of trade.**

The introduction of vessels propelled by sails for the purposes of commerce would necessarily cause a change in the constitution of the fleets assembled for the services of war; and this we find to have been the case.

**Richard Cœur de Lion.**

The expedition of Richard Cœur de Lion, in 1190, to join the crusade to the Holy Land, consisted of nine ships which are described as being of extraordinary size, 150 others of inferior dimensions, and only thirty-eight galleys. After the reduction of Cyprus, and the addition of the vessels captured there, with others which he had hired at Marseilles and in Sicily, his armament consisted of 254 "tall shippes, and about three score galliots." The increase was, therefore, almost wholly in the ships. This, together with the recorded fact, that he captured a Saracenic vessel of such size as to be capable of containing 1500 Saracens, and a large quantity of military stores, destined for the relief of Achon, tends to prove that the progress of naval architecture under the influence of the commercial powers of the Mediterranean, had been more rapid than in these northern seas, where the commerce was much more confined in its nature, and the nations bordering on which were in constant warfare with each other.

**Sovereignty of the seas.**

The Norman monarchs appear to have been very tenacious of their claim to the sovereignty of the narrow seas; and not only their claim, but their power to maintain their right, is admitted by the French historians. The Père Daniel sanctions the claim of Henry II. to this sovereignty.

**John.**

**Early origin of Portsmouth dock-yard.**

In the reign of John we find that the fleets of England were of such importance that the claim was extended; for it was then enacted, that if the masters of foreign ships should refuse to strike their colours, and thus pay homage to the English flag, such ships should be considered as lawful prizes. This monarch most carefully fostered the naval power of England; and it is in the records of the thirteenth year of this reign that we first read of any public naval establishment. There is in the close rolls published by the Record Commission, an order, which is dated the 29th of May 1212, from the king to the sheriff of the county of Southampton, in which he is directed without delay to cause the king's docks at Portsmouth to be enclosed by a good and strong wall, in order to protect the king's galleys and ships; and also to build storehouses against this wall for the preservation of the fittings and equipment of the said vessels; all of which works are to be performed under the direction of William, archdeacon of Taunton, and the greatest diligence is to be used, in order that the whole may be completed during the summer.

**Edward I.**

The naval power of England appears to have continued sufficient to maintain the sovereignty assumed by John. For the occurrence of predatory excursions by some Genoese during the reign of Edward I. caused all the nations of Europe, bordering on the sea, to appeal to the kings of England, whom they acknowledged to be in peaceable possession of the "Sovereign Lordship and Dominion of the Seas of England, and Islands of the same;" which proves that their claim was generally acknowledged. This document, Evelyn says, was still extant in his time, in the archives of the Tower. The right to the absolute sovereignty of the seas was maintained up to the reign of James I. Queen Elizabeth insisted on and maintained her power to refuse or grant passage through the narrow seas, according to her pleasure. In 1634 Charles I. asserted his right to their sovereignty; and in 1654 the Dutch were compelled, after a severe struggle, to submit to it, and consent to "strike their flags and lower their top-sails on meeting any ship of the English navy in the British seas;" which homage the commanders of English men-of-war were instructed to exact from all foreign vessels until so lately as the close of the last war, when it was judiciously abandoned, for reasons which we shall give in the words of Sir John Barrow. In his Life of Howe, with reference to Trafalgar, he says, "That battle, moreover, having so completely humbled the naval powers of France and Spain, suggested to the consideration of the Board of Admiralty, with the approbation of the government, the omission of that arbitrary and offensive article which required naval officers to demand the striking of the flag and lowering of the top-sail from every foreign ship they might fall in with. That invidious assumption of a right, though submitted to generally by foreigners for some centuries, could not probably have been maintained much longer, except at the cannon's mouth; and it was considered, therefore, that the proper time had come when it might both morally and politically be spontaneously abandoned."

**Error respecting the use of sailing vessels.**

It is generally supposed, that ships intended only for sailing were first built by the Genoese, and that not until the beginning of the fourteenth century. We rather incline to the opinion, that in the Mediterranean they date from an earlier period than this; and that although the general adoption of the galley in Western Europe had much checked the art of navigation by means of sails, it had never been wholly lost, but that sailing vessels, though probably very few in number, and imperfect in their rig, had been constantly in use. If we may judge from the few hints handed down to us by history, they were probably luggers, and were adopted for mercantile purposes along the coast of the Channel and the Bay of Biscay. In the north of Europe sails had never been discontinued, although the more warlike galleys of England and France had gradually prevented the incursions of the northern nations into these more southern seas. The beginning of the fourteenth century is, however, decidedly an epoch in the histories both of navigation and of naval architecture, and from it may be dated the progress of navigation by means of sails. It is generally supposed, that the "large ships" mentioned in the enumeration of the fleets of this period, were ships built only for sailing, and intended for those long voyages which the invention of the compass by Flavio Gioia, a Neapolitan, about the year 1300, had rendered of comparatively easy performance.

Mariner's compass.

Edward III.

It has been surmised that the compass was brought to Europe from the East about forty years previous to this date, by Paulus Venetus. It is certain that the Portuguese found the knowledge of the magnetic needle generally and long diffused among the eastern navies. Evelyn says that "it was, near eighty years after its discovery, unknown in Britain." This is not improbable, for there does not remain much record of maritime affairs in the interval between the reigns of John and Edward III. This monarch's reign was, after a most severe struggle with France for supremacy on the seas, the era of a series of naval triumphs, and both navigation and naval architecture made most decided advances.

Naval battle.

In an engagement which took place in 1340, the French force amounted to four hundred vessels, of which a hundred and twenty were "large ships," these being principally Genoese mercenaries. Edward III. commanded the English fleet in person, which consisted of but two hundred and sixty sail. The French are variously reported to have lost twenty and thirty thousand men, and two hundred vessels are said to have been captured. The loss to the English was only four thousand men. Two facts are elicited by the accounts of this engagement; one is, that there is no mention of galleys as forming any part of the fleets; the other is, that in the James of Dieppe, which was captured by the Earl of Huntingdon, four hundred persons were found slain; consequently the size of the vessel must have been very considerable.

Royal fleet.

Use of cannon.

In 1344 Edward summoned commissioners from all the ports, to meet in the metropolis, provided with the state of their "navies." The roll of this fleet is inserted in the first volume of Hakluyt, from a copy in the Cottonian Library. The total numbers were 710 ships, and 14,151 mariners; and there were thirty-eight foreign ships, with eight hundred and fifteen mariners. From this roll we learn that galleys had ceased to be used by England, either in her wars or in her commerce, as neither among the king's ships, nor among those furnished by merchants, is there any mention of them. This fleet was that engaged in the celebrated siege of Calais, and it was probably at this time that cannon were first employed by the English. Camden in his Remains says, "Certain it is, that King Edward III. used them at the siege of Calais in 1347."

Sizes of Edward's ships.

Although from the fact of there being a royal dock-yard at Portsmouth so early as the reign of John, it is probable that the kings of England were possessed of a navy almost from the conquest; yet this roll of Edward's fleet contains the first enumeration of ships belonging to the sovereign, and employed in the service of the state, which occurs in English history; and, consequently, it is from the reign of Edward III. that we must date the formation of a royal navy. The king's ships were twenty-five in number, and were manned by 419 mariners. It appears that the vessels belonging to the sovereign were inferior in force to many of those which were supplied by subjects; for the average number of the crews of the king's ships was seventeen men to each vessel, while the average of the fleet was rather above twenty. Of course these numbers only include the mariners employed in navigating the vessels, and not the soldiers to be afterwards embarked on board them. If we consider the simplicity of the rig of these ships, in comparison to the wilderness of canvass and cordage covering the tall masts of a modern merchantman, we have more reason to be astonished at the large number of hands employed, than at the smallness of the averages seventeen and twenty. There is good reason to suppose that the addition of the bowsprit to the rig of ships dates no farther back than late in the reign of Edward III., which is alone quite sufficient to prove the very imperfect state of the navigation at that period, and also to excite astonishment that, with such apparently inadequate means, so much was effected; for history would almost lead us to suppose, that for all the purposes of war and commerce, fleets as proudly or as industriously ploughed the main then as now, "with all appliances and means to boot." Plate CCCCXLV. fig. 3.

Richard II. First navigation act.

In the year 1381, the fourth of the reign of Richard II., the first navigation act was passed in England, for the encouragement of the naval interest, and the augmentation of our maritime power, by discountenancing the employment of foreign shipping. It enacted, "that for increasing the shipping of England, of late much diminished, none of the king's subjects shall hereafter ship any kind of merchandize, either outward or homeward, but only in ships of the king's subjects, on forfeiture of ships and merchandize, in which ships also the greater part of the crews shall be of the king's subjects." This act was not however enforced, permission being given to hire foreign shipping when there were no English ships in readiness.

Royal ships hired by merchants.

Henry IV.

Letter to Henry V.

We have said that the royal navy of England must date from the reign of Edward III. We have proof that it continued to be customary for the sovereign to possess ships; they were, however, used both for war and commerce. This practice, which does not at all militate against the existence of a royal navy, appears to have commenced when "large ships" were substituted for the galleys as vessels for war; and it long continued to be usual for merchants to hire shipping from the sovereign for commercial voyages. We learn from the proceedings of the privy council, which have been printed by the Record Commission, that in June of the year 1400, Henry IV. ordered his "new ship," together with such others as were in the port of London, to proceed against the enemy. There is also a letter in the Cottonian Library, which has been printed in Ellis's Collection of Letters, from John Alcetre to King Henry V. concerning a ship building for that monarch at Bayonne. The letter is of the date of 1419; and as it contains more minute details than might be expected to have descended to us from such an early period, we give the following extract. "At the makyng of this letter yt was in this estate, that ys, to wetyng xxxvj. strakys in hyth y bordyd, on the weche strakys hyth y layde xj. bemys; the mast beme ys yn leynthe xlvj. comyn fete, and the beme of the hameron afore ys in leynthe xxxix. fete, and the beme of the hameron hy hynde is in leynthe xxxiij. fete; fro the onemost ende of the stemne in to the post by hynde ys in leynthe a hondryd iij$^{\text{xx.}}$ and vj. fete; and the stemne ys in hithe iiij$^{\text{xx.}}$ and xvj. fete; and the post xlviij. fete; and the kele ys in leynthe a hondryd and xij. fete; hut he is y rotyt, and must be chaungyd."

We have also evidence of the existence of ships which helonged to the monarch, in contradistinction to ships which

“Libel of English policie.”

belonged to the “commons,” in the quaint rhymes of an anonymous author of the year 1433, which have been preserved by Hackluyt, termed “The Prologue of the processe of the Libel of English policie, exhorting all England to keepe the sea, and namely, the narrowe sea, shewing what profite commeth thereof, and also what worship and saluation to England, and to all Englishmen.”

> And if I should conclude all by the king
> Henrie the Fift, what was his purposing,
> Whan at Hampton he made the great dromons,
> Which passed other great ships of all the commons;
> The Trinitie, the Grace de Dieu, the Holy Ghost,
> And other moe, which as nowe bee lost.
> What hope ye was the king's great intent
> Of thoo shippes, and what in minde hee meant:
> It was not ellis; but that hee cast to be
> Lorde round about environ of the sea.

The term dromond is the corruption of a Levantine term, dromones, imported probably by the crusaders. The dromones were long row-galleys, but the adopted term dromond was applied generally to all large ships.

Henry's fleet.

There is a list of Henry's vessels in the fourth year of his reign, preserved in the proceedings of the privy council. His navy then consisted of three “large ships” or “grands niefs,” three “carracks,” eight barges, and ten balingers. In 1417 it was augmented to three “large ships,” eight “carracks,” six other ships, one barge, and nine balingers.

Early tonnage.

Again, in a letter preserved among the Cottonian manuscripts, and printed in Ellis's collection, we find that the Spaniards offered Henry V. two carracks for sale, one of which is described as of a tonnage equal to 1400, and the other to 1000 butts. So energetical was Henry V. in all things relating to his navy, and the consequent increase in the number of the royal ships during his reign was so great, as to have led to the error that before his time the sovereigns of England were not possessed of vessels, but relied wholly upon the aid to be gathered from the different ports of England, or to be hired from foreigners. This is evidently incorrect.

Neglect of the navy.

On the death of Henry V. a different line of policy appears to have been adopted; for in May 1423 the king's ships were all sold at Southampton, under a restriction that no foreigner could be a purchaser of them. But it appears that a long period did not elapse before the depressed state of the naval resources of the kingdom, consequent on this injudicious measure, attracted the attention of parliament. The following interesting quotation from the preface of the fifth volume of the Proceedings of the Privy Council, printed by the Record Commission, refers to this event. “In 1443 the attention of parliament was directed to this important part of the national defence (the naval force), and a highly curious ordinance was made for the safeguard of the sea. From February to November eight ships with forestages, or, as they were sometimes called then, as now, forecastles, armed with 150 men each, were to be constantly at sea. Every large ship was to be attended by a barge of eighty men, and a balinger of forty men. There were also to be ‘awaiting and attendant upon them’ four ‘spynes’ or ‘spinaces,’ with twenty-five men each. The whole number of men in these twenty-four ships was 2240.”

There is also in the same preface an account of the various kinds of ships which formed the navies of this period, a part of which we shall quote, and by the addition of some further information of the same nature, derived from Froissart, Monstrelet, and other sources, the reader will be enabled to form a tolerably correct opinion as to the state of naval architecture in England previous to and during the fifteenth century. Plate CCCCXLVI.

Ships.

*Ships.* “The burthen of the largest ships at that period probably did not exceed 600 tons, though some of them were certainly very large” as, for instance, the vessel built at Bayonne for Henry V., already mentioned. “One which belonged to Hull was released from arrest” (she having been pressed into the king's service), “because she drew so much water that she could not approach within two miles of the coast of Guienne, where the Duke of Somerset's army intended to disembark;” and several notices occur of ships of 300 and 400 tons and upwards. Some had three and others only two masts, with short topmasts, and a “forestage” or “forecastle,” consisting of a raised platform or stage, which obtained the name of castle from its containing soldiers, and probably from its having bulwarks. In this part of the ship it appears business was transacted; and in the reign of Edward III., if not afterwards, ships had sometimes one of these stages at each end, as ships “ove *chastiel devant et derere*” are then spoken of. (Plate CCCCXLVI. figs. 2, 3, 4, 5.) Lydgate, describing the fleet with which King Henry V. went to France after the battle of Agincourt, says,

> Fifteen hundred ships ready there be found,
> With rich sails and high topcastle.

This is a confusion of terms. The “topcastles” were not the forecastles, but were castellated enclosures at the mastheads, in which the pages to the officers were stationed during an engagement, in order to annoy the enemy with darts and other missiles; as is frequently mentioned in Froissart, and is represented in the illuminations to his work. Plate CCCCXLV. fig. 3.

Carracks.

*Carracks* “were vessels of considerable burthen, and were next in size to great ships, in which class they indeed were sometimes included. Their tonnage may be estimated by their being in some instances capable of carrying 1400 butts; and the sail of one afforded Chaucer a strange simile expressive of magnitude,

> And now hath Sathanas, saith he, a tayl
> Broder than of a carrike is the sayl.

Though occasionally armed and employed against the enemy, they were more generally used in foreign trade.”

Charnock says that the first carrack which was built in England was built for a merchant, John Tavenier, of Hull, who was consequently honoured by Henry VI. with distinguished favour; and she was licensed in 1449 with particular privileges to trade through the Straits of Morocco. The king also ordered her to be called the Grace Dieu Carrack. The license states her to have been built “by the help of God and some of the king's subjects.”

Barges.

*Barges* “were a smaller kind of vessel and of a different construction from ships, though, like them, they sometimes had forecastles. Those appointed to protect the seas in 1415 were of 100 tons burthen, and contained forty mariners, ten men-at-arms, and ten archers; whilst the ships employed on the same occasion were of 120 tons, and had forty-eight mariners, twenty-six men at arms, and twenty-six archers each. Four large barges and two balingers were capable of holding 120 men-at-arms and 480 archers and sailors.”

Balingers.

*Balingers* “were still smaller than barges, had no forecastle, and sometimes contained about forty sailors, ten men-at-arms, and ten archers.” Froissart makes frequent mention of “balniers,” “balleniers,” which he describes “as drawing little water, and being sent in advance to seek adventures, in the same manner as knights and squires, mounted on the fleetest horses, are ordered to scour in front of an enemy, to see if there be any ambuscades.” Monstrelet speaks of one vessel that was employed by Louis XI. to abduct the Count de Charolais, by the two names ballenier and balayer. It is not improbable, that the name is derived from the French word *baleine*, and that its origin was similar to that of our English name whaler. The whale-fishery in Biscay was of a very early date.

Galleys.

*Galleys* (Plate CCCCXLVI. fig. 1) “are frequently mentioned at a very early period; and in the 5th Rich. II. 1381, the Commons complained that no measures had been taken to resist the enemy, who had attacked the English at sea with their barges, galleys, and other vessels. In 1405 Henry IV. directed his council to apply to the king of Portugal to lend him his galleys to assist the English navy against the French."

In Sir Grenville Temple's Travels in Greece and Turkey, we find the following description of a Maltese galley, or, more correctly, galleas, made from an old model preserved there. "These galleys measured a hundred and sixty-nine feet one inch in length, and thirty-nine feet six inches in breadth. They had three masts with latine sails, and were propelled by forty-nine oars, each forty-four feet five inches long. Their armament consisted of one thirty-six pounder, two of twenty-four, and four of six, all on the forecastle, which in those days had in reality some appearance of a castle. On each side of the vessel, aft of the forecastle, were four six-pounders." The total crew, including galley-slaves, consisted of 549 persons.

Galleas.

The *Galleas* and the *Galleon* appear to have been successive improvements on the original galley, rendered necessary by the introduction of cannon into naval warfare. The artillery introduced on board the early galleys was placed either before or abaft the rowers, and to fire in the direction of the length. (Plate CCCCXLVII.) In the galleas, a description of vessel first used at the battle of Lepanto, guns were also placed between the rowers, to fire from the broadside. Evelyn describes the galleasses he saw at Venice (1645) as being "vessels to rowe of almost 150 foote long and thirty wide, not counting prow or poop, and contain twenty-eight banks of oares, each seven men, and to carry 1300 men, with three masts." In the galleon the oars ceased to be the principal means of propulsion, and if used at all, were only so as occasional aids. The galley and galleas had overhanging topsides for the accommodation of the oars. In the galleon, on the contrary, the topsides "tumbled home" to so extraordinary an extent, that the breadth at the water was twice that at the topside, a fashion which has continued, but in a much less degree, to the present time. Plate CCCCXLVIII.

Spynes or spynaces.

*Spynes* or *Spynaces*, "now called pinnaces, seem to have been large boats, capable of holding twenty-five men, and were probably used for swiftness. To these must be added crayers, bulks, gabarres or gabbars, a kind of flat-bottomed boat used in shallow rivers." The French still continue to apply the term "gabarre" to store-ships.

Playtes and smaller vessels.

"Playtes, cogships, whence perhaps cogs and coggles are derived; farecrofts, passagers, which were perhaps boats used between England and France; and cock-boats, a small boat which attended upon all kinds of ships. The whole of these vessels were employed in conveying goods or passengers, and most of them on rivers or in the coasting trade. The ships, carracks, barges, balingers, and galleys, were employed equally for commerce or for war. When sent against the enemy, soldiers were put on board of them; and it is most likely they were at all times partly manned by soldiers. In foreign voyages they usually sailed in convoys; and it was a very ancient custom for the masters and sailors to elect their own admiral."

Foists or foysts.

In Burchett's account of the unfortunate action in the Bay of Conquet in 1513, in which the Lord High Admiral, Sir Edward Howard, lost his life, four *foists* are mentioned as forming a part of the French force. They were probably vessels of a similar character with the galley, but smaller in size. About the beginning of the seventeenth century, "carracks," "galleons," and "tall shippes" appear to have become synonymous terms. Plate CCCCXLVIII.

Hulks.

The term hulk originally was applied in a different sense from that which is stated in the part of the foregoing remarks which we have quoted from the preface to the proceedings of the privy council. Frequent allusion is made to hulks in documents of the fifteenth and sixteenth centuries. In a letter from Sir Thomas Seymour to the privy council, dated the 13th of November 1544, when in command of the "shipes whyche was a poyntede to kepe the Narrow Sees," vindicating himself for putting back on account of a storm, there is the following passage, from which we might almost infer that hulk was a general name synonymous with ships. "Thre holkes that come after me colde nott gett syght thereof (the 'Eylle of Wyght),' tyll they warre in a bay on the est syde of the Eylle, of the whyche Mr Strowd, Bramston, and Battersebe of the garde, God rest their sowles, was in on of them, whyche holke brake all her ankeres and cabelles, and she brake all to peses on the shorr, and but 41 of 300 saved a lyve. The other two rode out the storme, whyche lasted all that nyght and the next day. My brother (Sir Hy Seymour) and John Roberds of the garde, tryde the sees all the furst nyght, and the next day cam into Dartemouth haven, wharre my brothers holke strake on a roke and brest all to peses; but God be praysede, all the men warre savede, savying thre; and a nother new holke that tryde the sees that nyght brake thre of her bemes, and with moche ado came into the Wyght."

Again, in a letter from Lord Viscount Lisle, Baron Malpas, the Lord High Admiral of England, to Henry VIII., we have an announcement, that "their is cum into the Downes 30 sayle of hulkses, whereof sum be tall shipes." And again, in a letter from the same to the Lord Chamberlain, Lord St John, he speaks of having detained "3 grate hulkes bound, as they say, for Lusshborne, the leste of y$^{m}$ 500 tunnes." And again, from the same to the same, he speaks of his former letter and the "goodly hulkes," and says, "sithens that tyme I have stayed other too, which in beautye and well appoynting are beyond the others. That I have last stayed ys a shipe of 600 at the least, and hath 5 toppes, and she ys of the town of Dansick, and ladon in Flanders for Lusshbourne."

State of mercantile shipping. William Canynge.

The importance of the mercantile shipping of England during the fifteenth century must have been considerable. About the middle of it flourished the celebrated William Canynge, a merchant of Bristol, who built the church of St Mary's, Redcliff, in that city, in which church he was buried in 1474. This man appears to have been much in advance of the rude times in which he lived. His mercantile transactions were on so extensive a scale, and carried on in vessels of such large size, that they must have had an important influence in improving the navies of the period. It is therefore not only as a fact of much historical interest, but as one which is intimately connected with and most probably materially affecting our subject, that we shall dwell on the information which has descended to us respecting him. He was a great patron of the arts, a friend and protector of genius, and eminent for his virtue and piety. From an inscription upon his tomb, a tradition has become current, that Edward IV. took 2470 tons of shipping from him, he having "forfeited the king's peace;" and for the obtaining of which again, it is stated that Edward accepted these ships instead of a fine of 3000 marks. The Itinerary of William of Worcester, preserved in the library of Benoett College, Cambridge, gives the names of Canynge's vessels, among which are the Mary and John of 900 tons, Mary Redcliff of 500 tons, and Mary Canynge of 400 tons. The same authority gives the names and tonnage of other large ships belonging to Bristol merchants, among which are the John, of 511 tons, and the Mary Grace, of 300 tons. If there be any truth in the tradition of the confiscation of the shipping, it is probable that the inscription on the tomb may refer to some act of Canynge's in favour of the house of Lancaster, as he appears to have enjoyed the favourable opinion of Henry VI. Another account, which, it is said, is authenticated by the original instrument in the Exchequer, states that this Canynge assisted Edward IV. with a loan, and received in return a license to have 2470 tons of shipping free of imposts. In Corry's History of Bristol it is said, "the commerce and manufactures of Bristol appear to have made considerable progress during the fifteenth century, about the middle of which flourished the celebrated Canynge. This extraordinary man employed 2853 tons of shipping and 800 mariners during eight years. Two recommendatory letters were written by Henry VI. in 1449, one to the master-general of Prussia, and the other to the magistrates of Dantzic, in which the king styles Canynge his beloved eminent merchant of Bristol."

**Doubts as to accuracy in estimating size of ships.**

Some doubt must always remain as to the actual size of the shipping of this remote period, as we cannot ascertain the bulk that was then considered as equivalent to a ton. It is probable that the tonnage was estimated according to the number of butts of wine that a vessel could carry. For we find references to ships sometimes by tonnage, and sometimes by the "portage" of so many butts.

**Henry VII.**

This, however, is only a question as to exactness of size. In whatever way measured, Canynge's ships must have been of very considerable dimensions. It is rather extraordinary, that at the unsettled period in question Bristol should have enjoyed such a state of commercial prosperity as the ownership of such shipping as that enumerated by William of Worcester necessarily involves. Bristol, for many centuries, was only second in mercantile importance to London; but the civil wars which distracted the kingdom during a great part of the fifteenth century must have much retarded the increase both of the military and the mercantile navy of England; and only when order was again re-established by the accession of Henry VII. to the throne in 1485, ought we to expect men's minds to revert from the internal excitement of party strife to external affairs.

**Progress of naval improvement.**

**Compass.**

**Astrolabe.**

**Netherlands.**

**Venice.**

In this interval, in which England was torn by the wars of the houses of York and Lancaster, naval science had made more rapid strides than in any previous period of similar duration. The compass was not only known, but was generally adopted. Navigators could take observations by the use of an instrument called the astrolabe, invented by the Portuguese. The Spaniards and Portuguese were sufficiently advanced in the art of navigation to sail on a wind, and their smaller vessels, at least, were adapted for this manœuvre. New maritime states had started into existence. The Netherlands, until then scarcely known, was under the Duke of Burgundy, the most formidable naval power in the north of Europe. "His navy," says Philip de Commines, "was so mighty and strong, that no man durst stir in those narrow seas for fear of it, making war upon the king of France's subjects, and threatening them everywhere; his navy being stronger than that of France and the Earl of Warwick joined together." Venice, in 1420, according to Denina in his Revolutions of Italy, supported 3000 merchant-ships, on board of which were 17,000 seamen. They employed 300 sail of superior force, manned by 8000 seamen; had forty-five carracks, with 11,000 men to navigate them; and her arsenals employed 16,000 carpenters. Portugal had pushed her discoveries round the Cape, and Spain had added America to the world.

**Portugal.**

**Spain.**

**Passage round the Cape of Good Hope.**

The progress of discovery by the Portuguese to the south and east, and by the Spaniards to the west, with the consequent rapid increase in the importance of these two powers, and the influence of their discoveries on the state of Europe, renders the fifteenth century probably the most important of modern history. In it was given the death-blow to the increase of the Saracenic power, and to that of the Mediterranean states. The Turk, the Venetian, and the Genoese, had hitherto been the monopolizers of the commerce of the east. The discovery of the passage round the Cape of Good Hope opened this trade to all nations. The commercial sceptre, and consequently the military sceptre, hitherto shared by the Turk, passed wholly from the infidel to the believer. The crescent sank before the cross.

**Its influence on naval architecture.**

There can be no doubt, also, that the "*tormentas*" of the "*grão Cabo de boa Esperãça,*" were a means of great improvement in naval architecture; for we find, that in consequence of the representations of Bartholomew Diaz, John II. of Portugal ordered ships to be constructed for the especial purpose of contending with the stormy seas of the Cape of Good Hope. The ships were built to form the squadron of Vasco de Gama, and were of small tonnage, from the very proper idea that small vessels were more adapted to prosecute researches in unknown seas than those of a large size, and consequent increased draught of water.

**Squadron of Vasco de Gama.**

The squadron of Vasco de Gama consisted of three ships and a caravella. One of the ships was of the burthen of two hundred tons, another one hundred and twenty, and the third one hundred; the caravella was of fifty tons. The largest of the ships was a victualler; the smallest was intended to prosecute discovery up creeks and shallows; and the other was for a display of force. As it is evident that it was not increase of dimensions which was to be the object in designing new vessels, the direction of improvement must have been towards perfecting their forms, strengthening their frames, and adding to the efficiency of their *materiel.* Portugal by these means became the most advanced state of Europe, in knowledge of the art of ship-building; for we find that it was long supposed that the passage to India required ships such as the Portuguese alone could build. Spain, in her career of discovery, conquest, and colonization across the mighty waters of the Atlantic, as if to assimilate the means to the vastness of her achievements, rapidly acquired the art of constructing ships of very large dimensions; and as long as she possessed a marine, her ships maintained this superiority.

**State of naval affairs in England.**

We have a curious instance of the light in which naval enterprises were considered in England at this time, notwithstanding the earnest desire of the monarch to re-establish his navy, which had necessarily suffered from the long civil wars. There is a letter from Henry VII. to the pope, preserved in the Cottonian Library, excusing himself from sending succour against the Turk, from which the following is a quotation. "The Galees commying from Vennes to England be commonly vij. monethes sailying, and sometimes more;" and again, "it should be May or they should be ready to saill, and it shall be the last end of Septembr or the said shippes shuld passe the Streits of Marrok; and grete difficultie to fynde any Maryners hable to take the rule and governance of the said shippes sailying into so jeopardous and ferre parties."

**Henri Grace à Dieu.**

There is a drawing (Plate CCCCXLIX.) extant in the Pepysian Library in Magdalen College, Cambridge, of the Henri Grace à Dieu, built by the order of Henry VII., which Charnock has engraved in his History of Marine Architecture, and argues as to the general authenticity of the representation. He says, "this vessel may be termed the parent of the British navy. This celebrated structure, the existence of which is recorded in many of the ancient chronicles, cost the king, by report, nearly 14,000 pounds."

**Early origin of naval terms.**

From this drawing may be traced the derivation of one or two names which have been preserved even to the present hour; as, for instance, the "yard-arm," no doubt from the ends of the yards being armed with an iron hook. The castellated work from which we have the term "forecastle" is earlier than this; and the buckler-ports are most probably derived from a yet earlier period, when the bucklers of the knights were ranged along the sides of the ship, as they are represented in the illustrations of Froissart, and of the early chroniclers, and even in the Bayeux Tapestry. Plate CCCCXLV.

"The masts were five in number, inclusive of the bowsprit, an usage which continued in the first-rates without alteration till nearly the end of the reign of King Charles I.; they were without division, in conformity with those which had been in unimproved use from the earliest ages. This inconvenience it was very soon found indispensably necessary to remedy, by the introduction of separate joints, or top-masts, which could be lowered in case of need."

The drawing shows two tiers of ports. The introduction of port-holes is said to be an improvement due to a French ship-builder of Brest, named Descharges, in the reign of Louis XII., and about the year 1500. If the drawing be authentic, the correctness of this appropriation of the merit of the introduction of port-holes may be questionable.

Again, if the drawing be a correct representation of the vessel, she would have been in danger of upsetting, excepting in calm weather, and when her course was with the wind. In fact, as yet the large ships of war of England were not at all adapted to sail on a wind, and were very ill provided with such sails as would enable them to do so; they had therefore nothing to fear from the result of a measure which could not be put into execution. The fleets of war of which we have hitherto written seldom ventured out of port excepting in the summer months, and then only when the wind was favourable to their intended course. But very shortly after the date of the building of the Henri Grace à Dieu, we shall find that great improvement took place, and that in the reign of Henry VIII. there is evidence to prove that sailing on a wind formed one of the qualities of the vessels composing his fleets. This fact appears to throw some doubt upon the correctness of the drawing, for it must have required ships widely different from any of which that would at all give an idea, to have performed the evolution of tacking or wearing; and as the Henri Grace à Dieu was in all probability the same ship that on the accession of Henry VIII. was called the Regent, she must have formed one in fleets which were capable of performing these manœuvres. It is true that she may have been altered to adapt her to these new requirements of an improved system of seamanship; and it must also be said, that she was burned in an action with the French fleet, which occurred as early as the fourth year of the reign of Henry VIII.

Henry VIII. Sailing on a wind.

Though it is out of the question that ships with the enormous top-hamper which, on the evidence of all the drawings extant, still continued to be the fashion, could have made much progress in sailing on a wind, the letters of the time extant corroborate the statement we have made; for they begin to contain references to this improvement in navigation. In a letter from Sir Edward Howard, "Lord Admiral," to King Henry VIII., upon the state of the fleet, A. D. 1513, preserved in the Cottonian Library, and published in Ellis's collection, we find the following passage: "Ye commanded me to send your grace word how every shipp dyd sail; and this same was the best tryall that cowd be, for we went both slakyng and by a bowlyn, and a cool acros and abouet in such wyse that few shippes lakkyd no water in over the lee wales." The Lord High Admiral Lisle, in one of his letters (1545), says the small vessels of his fleet could "lye best by a wynde;" and in 1567 we have conclusive proof that there were "fore and aft," indeed "cutter-rigged" vessels, on the British seas; as in a map of Ireland of that date, published in the state-papers, two such vessels are represented, for the purpose, apparently, of indicating regular packets from England to Ireland.

It has been very generally supposed, on the authority of Sir Walter Raleigh, that the "knowledge of the bowline" was a discovery in navigation made shortly before his time; but we think it is probable that there were, even from the time of the Northmen, craft so rigged as to be capable of sailing on a wind. Froissart mentions, in several instances, "a vessel called a Lio, which sails with all winds, and without danger;" and again, "a vessel called a Lin, which keeps nearer the wind than any other." Boats with a rig adapted for this manœuvre are also represented in engravings of a very early date. In the plates of Breydenbach's Voyage to Palestine, which was published in 1483, boats and small vessels are represented with lateen sails; and in Braun's *Civitates Orbis Terrarum*, published in 1572, sprit-sails are met with. It is quite certain, however, that sailing on a wind was by no means a general quality possessed by the ships of war, or to any extent even by the greater portion of the larger shipping, until about the reign of Henry VIII. We shall adduce one other instance, in the account of the loss of the Mari Rose, a ship of the "portage of 500 tons," not so much to corroborate the fact of sailing on a wind, as to show that the two innovations, the introduction of port-holes, and the "knowledge of the bowline," were, as we have just said, in advance of the qualities of the large ships of war of the time. Sir Walter Raleigh says that "in King Henry VIII.'s time, at Portsmouth, the Mari Rose, by a little sway of the ship in casting about, her ports being within sixteen inches of the water, was overset and lost."

Loss of the Mari Rose.

The loss of this ship has been the means of giving us another interesting insight into the comparatively low state of nautical skill in England at this period, namely, the middle of the sixteenth century. In a letter among the state-papers published under the direction of the Record Commission, addressed by the Duke of Suffolk to Sir William Pagett, "chief secretary to the kinge's highnes," dated the 23d of July 1545, and containing a schedule of things necessary to be had for the raising of the Mari Rose, one item is "fifty Venyzian maryners and one Venyzian carpenter;" the next item is "sixty Englisshe maryners to attende upon them." It would also appear that the attempt was to be made under the direction of an Italian, as the conclusion of the schedule is, "Item, Symond, petrone and master in the Foyst, doth aggrie that all thyngs must be had for the purpose aforesaid." The attempts however all failed; the wreck of the Mari Rose remains to this day at Spithead, and so lately as August 1836, several of her brass cannon, of most exquisite workmanship, were recovered from the sea by the enterprise and ability of an Englishman of the name of Deane.

Minutiæ of ship-building at this period.

We may obtain some idea of the detail of ship-building rather before this period, from an account of a vessel built by James IV. of Scotland, at the close of the fifteenth or the beginning of the sixteenth century. The extract is from Charnock, but he has not mentioned his authority. "The king of Scotland rigged a great ship, called the Great Michael, which was the largest and of superior strength to any that had sailed from England or France; for this ship was of so great stature, and took so much timber, that, except Falkland, she wasted all the woods in Fife which were oakwood, with all timber that was gotten out of Norway; for she was so strong, and of so great length and breadth, all the wrights of Scotland, yea, and many other strangers, were at her device by the king's command, who wrought very busily in her; but it was a year and a day ere she was completed. To wit, she was twelve score foot of length, and thirty-six foot within the sides; she was ten foot thick in the wall and boards, on every side so slack and so thick that no cannon could go through her. This great ship cumbred Scotland to get her to sea. From that time that she was afloat, and her masts and sails complete, with anchors offering thereto, she was counted to the king to be thirty thousand pounds expense, by her artillery, which was very great and costly to the king, by all the rest of her orders. To wit, she bare many cannon, six on every side, with three great bassils, two behind in her dock and one before, with three hundred shot of small artillery, that is to say, myand and battered falcon, and quarter falcon, flings, pestilent serpentens, and double dogs, with hagtor and culvering, corsbows and handbows. She had three hundred mariners to sail her, she had six score of gunners to use her artillery, and had a thousand men of war, by her captains, shippers, and quarter-masters."

Several of the writers of this period mention the fact of a

Large Swedish ship.

Swedish ship of extraordinary dimensions built in the middle of the sixteenth century, and which was burned in an action between the Swedes and Danes in 1564. Chapman has given an estimate of the dimensions of this vessel. She was called the Makalos (by Charnock, Megala). According to Chapman, she was 168 English feet in length and forty-three English feet in breadth, an immense vessel for that period. Her armament was 173 guns, sixty-seven only of which could be considered as cannon, the remainder being merely swivels.

Royal dock-yards.

We find that Henry VIII., deeply sensible of the necessity of a permanent and powerful naval force, established the navy-office, and also several dock-yards for building and repairing the ships of the royal navy. Among these were Woolwich, Deptford, and Chatham. He also greatly added to and improved the dock-yard at Portsmouth. He invited from foreign countries, particularly from Italy, the commercial cities of which were still in advance of the rest of Europe in the maritime arts, as many skilful foreigners as he could allure, either by the hope of gain, or by the honours and distinguished countenance he paid to them. The following extract is from a report made to James I. in the year 1618, and published in the Archæologia. It was made in answer to a commission issued by that monarch to the several master-builders. The date of the report is rather in advance of our history; but we insert it here because the information it contains is of the time on which we are writing; as, while it confirms the statement we have just made, it informs us on the force of the royal navy during the reigns of Edward and of Mary, the period at which we have now arrived.

Edward VI.

The minority of Edward VI., and the civil and religious strife which distracted the kingdom during the reign of Mary, depressed the resources of the state, and evidently much checked the progress of its maritime strength. The report says, "In former times our kings have enlarged their dominions rather by land than sea forces, whereat even strangers have marvelled, considering the many advantages of a navy; but since the change of weapons and fight, Henry VIII., making use of Italian shipwrights, and encouraging his own people to build strong ships of war, to carry great ordnance, by that means established a puissant navy, which in the end of his reign consisted of seventy vessels, whereof thirty were ships of burthen, and contained in all 10,550 tons, and two galleys. The rest were small barks and row-barges, from eighty tons downwards to fifteen tons, which served in rivers and for landing of men. Edward VI., in the sixth year of his reign, had but fifty-three ships, containing in all 11,005 tons, with 7995 men, whereof only twenty-eight vessels were above eighty tons each. Queen Mary had but forty-six of all sorts."

Defects of the ships of this period.

There is one peculiarity about the fleets of this time, which exemplifies the defects of their design in a very remarkable feature. It is, that the ships built for the royal navy appear only to have been adapted for the lodgment of the soldiers and mariners, with their implements of war, and the necessary stores for navigation. The provisions were carried in an attendant vessel, called a "victualler," of which there was one attached to each of the large ships of war in the fleet, or to several of the smaller size. The hold appears to have been principally occupied by the "cook-room," the inconvenience of which arrangement, though much complained of, was general when Sir Walter Raleigh, in his Discourse on the Royal Navy and Sea-Service, recommended that it should be removed to the forecastle; and even so lately as 1715, several men of war had "cook-rooms" in their holds. There is also no doubt that the enormous quantity of ballast which was rendered necessary by the immense top-hamper of these ships, and the space which it occupied from being shingle, left but little room for the stowage of any quantity of provisions. In the ships built for commerce, this defect does not appear to have existed, as in fleets composed of the king's and of private shipping, those ships only which belonged to the royal navy had these attendant victuallers. We also know that the cook-rooms in the merchant-shipping were under the forecastle; and they had less top-hamper, as less accommodation was required for officers.

Epoch in naval architecture.

Although we may comment on the comparative inefficiency of the vessels, we cannot but perceive that we have entered that period in the history of naval architecture and of navigation, in which, though still in their infancy, these arts may be considered as perfect in all but the maturity to be acquired by the experience of years. The mariner's compass was known; the theory of taking observations was understood, and the practice of it in the course of being perfected; and therefore the longest voyages could be undertaken with comparative certainty and safety. Besides this, the ships, though still imperfect, were becoming gradually manageable machines, and had ceased to be the cumbrous masses of the preceding ages, which, with few exceptions, were capable of little more than of being driven before the wind.

Three epochs in the maritime history of England.

If we consider the contents of the foregoing pages, there will appear to be three epochs in the maritime history of England; the first commencing with the introduction of galleys by Alfred, and ending with the reign of Edward III., before whose time these galleys and vessels propelled by oars were the chief instruments of navigation; the second ending with the reign of Henry VII., during which period, though sailing vessels were used for the purposes both of war and commerce, they were comparatively at the mercy of the winds, and, speaking generally, could sail only when they blew both fairly and gently; the third epoch we have already noticed. And henceforward we find the sister arts of navigation and naval architecture, if not always making rapid progress towards their present improved state, at least with no existing impediment to their advance towards that comparative perfection.

Elizabeth. Action with Spanish Armada.

We have seen, from the extract of the report of the builders, the state of the navy during the reigns of Edward VI. and of Mary. We know, therefore, that when Elizabeth ascended the throne, the marine of England, both military and mercantile, was in a very depressed state. The successful enterprise of Drake, and the fear of the Spanish Armada, aroused the energies of the country, and the force collected to resist the invasion amounted to 197 vessels of various descriptions, of the aggregate burthen of nearly 30,000 tons; thirty-four of which, measuring together 12,600 tons, composed the royal navy. It is true, that by far the larger portion were of small force. One only, the Triumph, was of 1100 tons; another, the White Bear, was of 1000 tons; two were of 800 tons, three of 600, six of 500, and five of 400; sixty-six were under 100 tons; and fifteen were victuallers, of which the tonnage is not mentioned. There are also seven other vessels included in the 197, which have no tonnage assigned them; but they must have been of small size, the number of mariners on board the whole seven being only 474. We have very conclusive means of comparing the Spanish with the English ships, and also of judging how very little naval arrangements were then understood, from their imperfect state even on board a fleet which had occupied the whole attention of the Spanish authorities for a space of three years, exemplified in the following anecdote; Burchett, in his account of the action of the 23d of July 1588, says, "The great guns on both sides thundered with extraordinary fury, but the shot from the high-built Spanish ships flew over the heads of the English without doing any execution; one Mr Cock being the only Englishman who fell, while he was bravely fighting against the enemy in a small vessel of his own."

Three-decked ships.

The Spaniards appear to have been the first to introduce a third tier of guns, the earliest mention of a three-decker being the Philip, a Spanish ship engaged in the action off the Azores in 1591, with the Revenge, commanded by Sir Richard Greenvil. The following armament of the Philip is extracted from a most spirit-stirring account of this tremendous action, which was written by Sir Walter Raleigh, and has been preserved by Hackluyt. "The Philip carried three tire of ordnance on a side, and eleven pieces in euerie tire. She shot eight forth right out of her chase, besides those of her stern portes."

We do not appear to have followed the example set by the Spaniards; for, during the long reign of Elizabeth, the ships of the royal navy were not much, if at all, increased in their dimensions, which was probably owing to the triumphant successes of her fleets, though, as we have seen, they were composed of ships generally much smaller in size than those opposed to them. We find from the list of the royal navy at the time of her death, in 1603, given by Sir William Monson in his tracts, that of forty-two ships composing the navy, there were then only two ships of 1000 tons, three of 900, three of 800, two of 700, four of 600, four of 500, and there were eight under 100 tons burthen. Two of these ships, the Triumph and the White Bear, are rated in this list each at 100 tons less burthen than in the list of the fleet in the year 1588, which we have already noticed.

James I.
Report of commission.

Shortly after the accession of James to the throne, several commissions were appointed to inquire into the state of the navy. From that of the year 1618, a very voluminous report emanated, of which the following is an extract, that affords an example of the state of knowledge on naval architecture at that time. "The next consideration is the manner of building, which in shipps of warr is of greatest importance, because therein consists both their sayling and force. The shipps that can saile best can take or leave (as they say), and use all advantages the winds and seas does afford; and their mould, in the judgment of men of best skill, both dead and alive, should have the length treble to the breadth, and breadth in like proportion to the depth, but not to draw above sixteen foote water, because deeper shipps are seldom good saylers, and ever unsafe for our rivers, and for the shallow harbours, and all coasts of ours, or other seas. Besides, they must bee somewhat snugg built, without double gallarys, and too lofty upper workes, which overcharge many shipps, and make them coome faire, but not worke well at sea.

"And for the strengthening the shipps, wee subscribe to the manner of building approved by the late worthy prince, the lord admll., and the officers of the navy (as wee are informed), on those points.

"1. In makeing 3 orlopes, whereof the lowest being placed 2 foote under water, both strengtheneth the shipp, and though her sides bee shott through, keepeth it from bildgeing by shott, and giveth easier meanes to finde and stopp the leakes.

"2. In carrying their orlopes whole floored throughout from end to end, without fall or cutting off ye wast, which only to make faire cabbins, hath decayed many shipps.

"3. In laying the second orlope at such convenient height that the portes may beare out the whole fire of ordinance in all seas and weathers.

"4. In placeing the cooke roomes in the forecastle, as other war shipps doe, because being in the midshipps, and in the hold, the smoake and heate soe search every corner and seame, that they make the okam spew out, and the shipps leaky, and soone decay; besides, the best roome for stowage of victualling is thereby soe taken up, that transporters must be hyred for every voyage of any time; and, which is worst, when all the weight must bee cast before and abaft, and the shipps are left empty and light in the midst, it makes them apt to sway in the back, as the Guardland and divers others have done."

This commission was followed by several others during this and the succeeding reign, and from their reports arose many regulations tending much to the improvement of the navy, although the expenses incurred were, ostensibly at least, in part the means of causing the subsequent revolution.

Mercantile shipping of this period.

Trade's Increase.

In the early part of the reign of James I. the mercantile navy of England was reduced to a very low state, most of the commerce being carried on in foreign bottoms. The incitement offered by the advantageous trade which the Dutch had long engaged in to India at length aroused the nation, and the formation of the East India Company, which was the act of James, was followed by the building of the largest ship that had yet been constructed for the purposes of commerce, at least in England. The king dined on board of her, and gave her the name of the Trade's Increase. She is reported to have been of the burthen of 1200 tons. The impetus once given, before the end of the reign of James an important mercantile navy was owned by British merchants.

Shipwrights' Company.

Draughts of ships of royal navy.

Another interesting fact connected with this reign is the founding of the Shipwrights' Company, in the year 1605, and which was incorporated by a charter granted to the "Master, Warden, and Commonality, of the Art or Mystery of Shipwrights," in May 1612. Mr Phineas Pett, of whom we shall presently speak, was the first master. The draughts for the ships of the royal navy were subsequently ordered to be submitted to this company for approval previously to being built from. They also had jurisdiction over all builders, whether of the royal navy or of merchant shipping.

Royal Prince.

In 1610 the Royal Prince was launched; she was the largest ship which at that time had been built in England, and was also a most decided improvement in naval architecture. The great projection of the prow, a remnant of the old galley, was for the first time discontinued, and the stern and quarters assimilated more to those of a modern ship than to any which had preceded her. She is thus described in Stow's Chronicles: "A most goodly ship for warre, the keel whereof was 114 feet in length, and the cross beam was 44 feet in length; she will carry 64 pieces of ordnance, and is of the burthen of 1400 tons. The great workmaster in building this ship was Master Phineas Pett, Gentleman, some time master of arts at Emanuel College, Cambridge."

Phineas Pett.

The Petts.

The same gentleman, Mr Phineas Pett, continued the principal engineer of the navy during the reign of Charles. The family of the Petts were the great instruments in the improvement of the navy, and, if the term may be allowed, of modernizing it, by divesting the ships of much of the cumbrous top-hamper entailed on them from the castellated defences which had been necessary in, and which yet remained from, the hand-to-hand encounters of the middle ages; and it is probable that, but for the taste for gorgeous decoration which prevailed during the seventeenth century, this ingenious family would have been able to effect much more; as it was, they decidedly rendered England preeminently the school for naval architecture during the time they constructed its fleets. This family can be traced as principal engineers for the navy from about the middle of the fifteenth century to the end of the reign of William III.

First frigate.

Evelyn, in his Diary, relating a conversation, says, "Sir Anthony Deane mentioned what exceeding advantage we of this nation had by being the first who built frigates, the first of which ever built was that vessell which was afterwards called the Constant Warwick (built in 1646), and was the work of Pet of Chatham, for a trial of making a vessell that would sail swiftly. It was built with low decks, the guns lying near the water, and was so light and swift of sailing, that in a short time she had, ere the Dutch war was ended, taken as much money from privateers as would have laden her." The dimensions of this vessel are given in Pepys's Miscellanies as follows: Length of the keel eighty-five feet, breadth twenty-six feet five inches, depth thirteen feet two inches, and 315 tons burthen; her "highest number of guns" thirty-two, and of crew 140.

Peter Pett.

Peter Pett, who built the Constant Warwick, was the son

First three-decker.

of Phineas Pett. He caused the fact of his being the inventor of the frigate to be recorded on his tomb. He was also the builder of the Sovereign of the Seas, in 1637, which was the first three-decker built in England. Her length over all is stated to have been 232 feet, her length of keel 128 feet, her main breadth forty-eight feet, and her tonnage 1637. Heywood describes her in the following terms: "She hath three flush deckes and a forecastle, an halfe decke, a quarter decke, and a round-house. Her lower tyre hath thirty ports, which are to be furnished with demi-cannon and whole cannon throughout, being able to beare them. Her middle tyre hath also thirty ports for demi-culverin and whole culverin. Her third tyre hath twentie-sixe ports for other ordnance. Her forecastle hath twelve ports, and her halfe decke hath fourteene ports. She hath thirteene or foureteene ports more within board for murdering peeces, besides a great many loope-holes out of the cabins for musket shot. She carrieth, moreover, ten peeces of chase ordnance in her right forward, and ten right aff; that is, according to land service, in the front and the reare. She carrieth eleaven anchors, one of them weighing foure thousand foure hundred, &c.; and according to these are her cables, mastes, sayles, cordage, which, considered together, seeing Majesty is at this infinite charge, both for the honour of his nation, and the security of his kingdome, it should bee a spur and encouragement to all his faithful and loving subjects to bee liberall and willing contributaries towards the ship money." Plate CCCCXLIX.

Of this ship, Fuller, in his Worthies, says, "The Great Sovereign, built at Woolwich, a leiger ship for state, is the greatest ship our island ever saw; but great medals are made for some grand solemnity, while lesser coin are more current and passable in payment." She was afterwards cut down one deck, and remained in the service, with the character of the best man-of-war in the world, until the year 1696, when she was accidentally burnt at Chatham.

Sir Walter Raleigh's works: Invention of Shipping; Concerning the Royal Navy and Sea-Service.

About this time, 1650, appeared the first work connected with naval improvement ever written in this country, and by no less celebrated an author than Sir Walter Raleigh. It is very probable that his two discourses, the one on the Invention of Shipping, the other Concerning the Royal Navy and Sea-Service, had great influence in creating the interest which was evidently taken about this period in the improvement of the navy. Sir Walter says, "Whosoever were the inventors, we find that every age had added somewhat to ships and to all things else. And in my owne time the shape of our English ships hath been greatly bettered. It is not long since the striking of the top-mast (a wonderfully great ease to great ships both at sea and harbour) hath been devised. Together with the chaine-pumpe, which takes up twice as much water as the ordinary did, we have lately added the bonnett and the drabler. To the courses we have devised studding-sayles, top-gallant-sayles, sprit-sayles, top-sayles. The weighing of anchors by the capstane is also new. We have fallen into consideration of the length of cables, and by it we resist the malice of the greatest winds that can blow; witnesse our small Milbroke men of Cornewall, that ride it out at anchor half seas over betweene England and Ireland all the winter quarter; and witnesse the Hollanders that were wont to ride before Dunkirke with the wind at north-west, making a lee-shore in all weathers; for true it is that the length of the cable is the life of the ship in all extremities; and the reason is, because it makes so many bendings and waves as the ship riding at that length is not able to stretch it, and nothing breaks that is not stretched. In extremity, we carry our ordnance better than we were wont, because our nether-overloops are raised commonly from the water, to wit, betweene the lower part of the port and the sea. We have also raised our second decks, and given more vent thereby to our ordnance, tying in our nether-overloope.

"We have added crosse pillars in our royall ships to strengthen them, which being fastened from the kelson to the beams of the second decke, keepe them from setling or from giving away in all distresses.

"We have given longer floares to our ships than in elder times, and better bearing under water, whereby they never fall into the sea after the head, and shake the whole body, nor sinck sterne, nor stoope upon a wind, by which the breaking loose of our ordnance, or the not use of them, with many other discommodities, are avoided. And to say the truth, a miserable shame and dishonour it were for our shipwrights, if they did not exceed all other in the setting up of our royall ships, the errors of other nations being farre more excusable than ours. For the kings of England have for many years been at the charge to build and furnish a navy of powerfull ships for their owne defence, and for the wars only; whereas the French, the Spainards, the Portugalls, and the Hollanders (till of late), have had no proper fleete belonging to their princes or states.

"Only the Venetians for a long time have maintained their arsenal of gallyes, and the kings of Denmark and Sweden have had good ships for these last fifty years. I say, that the forenamed kings, especially the Spainards and Portugalls, have ships of great bulke, but fitter for the merchant than the man of warre, for burthen then for battaile. ...Although we have not at this time 135 ships belonging to the subjects of 500 tuns each ship, as it is said we had in the 24th yeare of Queen Elizabeth, at which time also, upon a generall view and muster there were found in England, of all men fit to beare arms, eleaven hundred and seventy-two thousand; yet are our merchants' ships now farre more warlike and better appointed than they were, and the royal navy double as strong as then it was....We have not therefore lesse force than we had, the fashion and furnishing of our ships considered; for there are in England at this time 400 saile of merchants fit for the wars, which the Spainards would call gallions; to which we may add 200 saile of crumsters or hoyes, of Newcastle, which each of them will bear six demi-culverins, and foure sakers, needing no other addition of building than a slight spar-decke fore and afte, as the seamen call it, which is a slight decke throughout. The 200 which may be chosen out of 400, by reason of their ready staying and turning, by reason of their windwardnesse, and by reason of their drawing of little water, and they are of extreame vantage neere the shoare, and in all bayes and rivers to turn in and out; these, I say, alone, well manned and well conducted, would trouble the greatest prince in Europe to encounter in our seas; for they stay and turn so readily, as, ordering them into small squadrons, three of them at once may give their broad-sides upon any one great ship, or upon any angle or side of an enemy's fleet. They shall be able to continue a perpetuall volley of demi-culverins without intermission, and either sink or slaughter the men, or utterly disorder any fleete of crosse sailes with which they encounter.

"I say, then, if a vanguard be ordained of these hoyes, who will easily recover the wind of any other ships, with a battaile of 400 other warlike ships, and a reare of thirty of his majestie's ships to sustaine, relieve, and countenance the rest (if God beat them not), I know not what strength can be gathered in all Europe to beat them. And if it be objected that the states can furnish a farre greater number, I answer, that his majestie's forty ships, added to 600 before named, are of incomparable greater force than all that Holland and Zeeland can furnish for wars."

Ships of royal navy inferior to merchant-ships.

In the foregoing extract, we have strong evidence that the ships of the royal navy were generally inferior to those employed by the merchant-service, in the essential qualifications of being weatherly. This is exactly the conclusion that might be arrived at from the consideration, that a private individual would dispense with all that superabundance of top-hamper which was entailed on the ships of the royal navy, by the accommodation required for the numerous officers and gentlemen generally embarked on board them, and also by the mania for gorgeous decorations. This mania is well exemplified by the fact, that of the Sovereign of the Seas it is stated, " she beareth five lanthornes, the biggest of which will hold ten persons to stand upright, and without shouldring one another."

Sir Walter Raleigh, in his Discourse on the Royal Navy and Sea-Service, adverts to the same subject. He says, " We find by experience, that the greatest ships are lesse serviceable, goe very deep to water, and of marvellous charge and fearefull cumber, our channells decaying every yeare. Besides, they are lesse nimble, lesse maineable, and very seldome imployed. *Grande navio, grande fatica*, saith the Spainard; a ship of 600 tons will carry as good ordnance as a ship of 1200 tons; and though the greater have double the number, the lesser will turne her broad sides twice before the greater can wend once; and so no advantage in that overplus of ordnance. And in the building of all ships, these six things are principally required. 1. First, that she be strong built; 2. Secondly, that she be swift; 3. Thirdly, that she be stout sided; 4. Fourthly, that she carry out her guns all weather; 5. Fifthly, that she hull and try well, which we call a good sea ship; 6. Sixthly, that she stay well when bourding and turning on a wind is required.

" 1. To make her strong, consisteth in the truth of the workeman and the care of the officers.

" 2. To make her sayle well, is to give a long run forward, and so afterward done by art and just proportion. For, as in laying out of her bows before, and quarters behind, she neither sinck into nor hang in the water, but lye cleare off and above it; and that the shipwrights be not deceived herein (as for the most part they have ever been), they must be sure that the ship sinck no deeper into the water than they promise, for otherwise the bow and quarter will utterly spoile her sayling.

" 3. That she be stout, the same is provided and performed by a long bearing floore, and by sharing off above water even from the lower edge of the ports.

" 4. To carry out her ordnance all weather, this long bearing floore, and sharing off from above the ports, is a chiefe cause, provided alwayes that your lowest tyre of ordnance must lye foure foot cleare above water when all loading is in, or else those your best pieces will be of small use at the same in any growne weather that makes the billoe to rise, for then you shall be enforced to take in all your lower ports, or else hazard the ship.

" 5. To make her a good sea ship, that is, to hull and trye well, there are two things specially to be observed; the one that she have a good draught of water, the other that she be not overcharged, which commonly the king's ships are, and therefore in them we are forced to lye at trye with our maine course and missen, which, with a deep keel and standing streake, she will performe.

" 6. The hinderance to stay well is the extreame length of a ship, especially if she be floaty and want sharpnesse of way forwards; and it is most true, that those over-long ships are fitter for our seas than for the ocean; but one hundred foot long, and five and thirty foot broad, is a good proportion for a great ship. It is a speciall observation, that all ships sharpe before, that want a long floore, will fall roughly into the sea, and take in water over head and ears.

" So will all narrow quartered ships sinck after the tayle. The high charging of ships is it that brings them all ill qualities, makes them extreame leeward, makes them sinck deep into the water, makes them labour, and makes them overset. Men may not expect the ease of many cabbins, and safety at once, in sea-service. Two decks and a half is sufficient to yield shelter and lodging for men and mariners, and no more charging at all higher, but only one low cabbin for the master. But our marriners will say, that a ship will beare more charging aloft for cabbins, and that is true, if none but ordinary marryners were to serve in them, who are able to endure, and are used to, the tumbling and rowling of ships from side to side when the sea is never so little growne; but men of better sort and better breeding would be glad to find more steadinesse and lesse tottering cadge work. And albeit, the marriners doe covet store of cabbins, yet indeed they are but sluttish dens, that bread sicknesse in peace, serving to cover stealths, and in fight are dangerous to teare men with their splinters."

Fuller's Worthies.

In Fuller's Worthies, we have also a short summary of the comparative qualities of the ships of different nations in the middle of the seventeenth century. It is as follows: " First, for the Portugal, his carvils and caracts, whereof few now remain (the charges of maintaining them far exceeding the profit they bring in); they were the veriest drones on the sea, the rather because formerly their seeling was dam'd up with a certain kind of morter to dead the shot, a fashion now by them disused.

" The French, however dexterous in land-battles, are left-handed in sea-fights, whose best ships are of Dutch building. The Dutch build their ships so floaty and buoyant, they have little hold in the water in comparison to ours, which keep the better winde, and so outsail them.

" The Spanish pride hath infected their ships with loftiness, which makes them but the fairer markes to our shot. Besides, the winde hath so much power of them in bad weather, so that it drives them two leagues for one of ours to the leeward, which is very dangerous upon a lee shore.

" Indeed the Turkish frigots, especially some thirty-six of Algier, formed and built much nearer the English mode, and manned by renegadoes, many of them English, being already too nimble heel'd for the Dutch, may hereafter prove mischievous to us, if not seasonably prevented."

Rise of Dutch naval power.

During the early part of the seventeenth century, the Dutch navy rapidly increased in importance. Their success in having wrested from the Portuguese a share of the commerce of the east, emboldened them, in the then depressed state of the Spanish marine, to make a similar attempt on the west, and endeavour to establish settlements in South America.

The wars with Spain, in which they were consequently engaged, had such an important effect in establishing their maritime power, that in 1650 their navy consisted of 120 vessels fitted for war, seventy of which had two tiers of guns; and their fleet was in all respects the most efficient in Europe.

Evelyn's Navigation and Commerce.

Evelyn, in his tract on Navigation and Commerce, speaking of the fisheries, says, " Holland and Zeeland alone should, from a few despicable boats, be able to set forth above 20,000 vessels of all sorts, fit for the rude seas, of which more than 7000 are yearly employed upon this occasion. 'Tis evident that by this particular trade they are able to breed above 40,000 fishermen and 116,000 mariners, as the census (1639) has been accurately calculated."

The tremendous struggle in which they were enabled by these means to engage with us shortly after this period, in consequence of the injurious operation of the navigation act on their commerce, had a most influential effect on the improvement of our navy, which at the commencement of the contest was very unequal to that of the Dutch; and it is probable that this war was the means of enabling us to contend triumphantly against the immense and unexpected attempts of Louis XIV. to wrest the sceptre of the seas from our grasp.

Charles I.

The sovereigns of the house of Stuart, without exception, appear to have devoted much attention to the improvement of the navy. Charles I. may be almost said to have lost both crown and life in consequence of these efforts; nor would it be doing justice to Cromwell to omit mention

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of the energy with which he took advantage of the all but despotic power which he possessed to increase his naval force. For this purpose not only many ships were built during the protectorate, but numbers of merchant-vessels were bought for the service of the state.

Charles II. His personal attention to ship-building and naval affairs.

After the restoration, Charles II. paid great personal attention even to the minutiæ of his navy, as we find by the following curious extract from a letter of his to Prince Rupert, preserved in the state-papers, and also by continual references to his naval predilections in Evelyn's and Pepys's Memoirs and writings. The letter is dated 4th August 1673. It says, "I am very glad the Charles does so well; a gerdeling this winter when she comes in will make her the best ship in England; next summer, I believe, if you try the two sloops that were builte at Woolidge that have my invention in them, they will outsail any of the French sloops. Sir Samuel Mooreland has now another fancy about weighing anchors; and the resident of Venice has made a model also to the same purpose. We have not yet consulted them with Mr Tippet nor Mr Deane; but hope when they are well considered, we may find one out of them that will be good."

Sir Anthony Deane.

In Pepys's Diary, 19th May 1666, we find the following notice relating to one of the gentlemen mentioned in the above letter: "Mr Deane and I did discourse about his ship the Rupert, which succeeds so well, as he has got great honor by it, and I some by recommending him. The king, duke, and every body, say it is the best ship that was ever built. And then he fell to explain to me his manner of casting the draught of water which a ship will draw beforehand, which is a secret the king and all admire in him; and he is the first that hath come to any certainty beforehand of foretelling the draught of water of a ship before she be launched." This gentleman appears therefore to have been the first who applied mathematical science to naval architecture in this country. Pepys also says, "another great step and improvement to our navy, put in practice by Sir Anthony Deane," was effected in the Warspight and Defiance, which were "to carry six months' provisions, and their guns to lie 4½ feet from the water." This was in 1665.

First application of mathematical calculation to naval architecture.

History.

We have hitherto in our historical sketch several times adverted to the probability that the merchant-shipping of England were superior in their sea-going qualities to those composing the royal navy. In a "Discourse touching the Past and Present State of the Navy," by Sir Robert Slingeby, knight-baronet, and comptroller of the navy, dated 1669, we have the following interesting statement, which points to a reason why this superiority of the merchant-shipping may have existed. "But since these late distractions began at home" (the Commonwealth), "forreigne trade decayed, and merchants so discouraged from building, that there hath been scarce one good merchant-ship built these twenty years past; and of what were then in being, either by decayes or accident, there are very few or none remaining. The merchants have found their private conveniences in being convoyed att the publick charge; they take noe care of making defence for themselves if a warr should happen." Yet he says in the time of Charles I. "the merchants continued their trade during the wars with France and Spain, if there could but two or three consort together, not caring who they met," they being little inferior in strength or burthen to the ships of the royal navy. The Discourse expresses much regret at this decay in the importance of the mercantile shipping, and recommends that measures should be taken to check the evil.

Sir Robert Slingeby.

Decay of mercantile navy.

About 1684 Sir Richard Haddock, comptroller of the navy, adopted the example already set by Mr, afterwards Sir Anthony Deane, and directed an inquiry to be made as to "the number of cube feet that are contained in the bodyes of several draughts to their main water-line, when all materialls are on board fitt for saileing." The result of this inquiry was a very voluminous statement of the weights which made up the whole displacement of the fourth, fifth, and sixth rate ships, including minute details of their masts, yards, armament, &c. accompanied by perfect drawings of each ship. The original document is now in the possession of the writer of this article, having successively belonged to Sir Jacob Ackworth, Sir Jacob Wheate, and Mr Edward Hunt. The following table contains the dimensions and displacements, &c. of each class.

Sir Richard Haddock.

First analysis of the royal navy.

*Table of Dimensions, from a Manuscript dated* 1684.

| | A First Fourth-rate near the largest dimensions. | A Second Fourth-rate near the dimensions of the Adventure. | A Fifth-rate of the largest dimensions. | A First Sixth-rate. | A Second Sixth-rate. | A Sixth-rate of the largest dimensions. | A Sixth-rate of the old fashion. |
|---|---|---|---|---|---|---|---|
| | Feet. In. | Feet. In. | Feet. In. | Feet. In. | Feet. In. | Feet. In. | Feet. In. |
| Length on the gun-deck from the rabbitt of the stem to the rabbitt of the post | 124 6 | 118 6 | 103 9 | 87 6 | 70 0 | 92 6 | 93 0 |
| Maine breadth to the outside of the outboard planke | 35 0 | 32 9 | 23 8 | 23 6 | 21 0 | 23 6 | 22 9 |
| Depth in hold from the seeling to the upper side of the beame | 14 0 | 13 2 | 11 4 | 10 9 | 9 10 | 11 9 | 10 0 |
| Breadth at the afte side of the maine transome | 21 0 | 19 4 | 18 0 | 14 0 | 13 0 | 14 0 | 15 0 |
| Height on the gun-deck from planke to planke: afore | 5 9 | 6 0 | 5 9 | 5 7 | 5 6 | ... | ... |
| midships | 6 0 | 6 0 | 6 0 | ... | ... | ... | ... |
| abafte | 6 6 | 8 3 | 6 7 | 6 3 | 8 2 | ... | ... |
| The center of the fore mast from the rabbitt of the stern | 13 6 | 12 9 | 9 10 | 7 8 | 6 6 | 10 0 | 9 8 |
| The center of the maine mast from the rabbitt of the stern | 69 0 | 62 0 | 54 8 | 45 0 | 36 0 | 50 0 | 49 6 |
| The center of the mizion mast from the rabbitt of the stern | 102 0 | 96 9 | 84 0 | 71 0 | 57 0 | 73 0 | 74 0 |
| Draft of water: afore | 14 6 | 13 6 | 12 0 | 9 6 | 6 6 | 10 0 | 8 0 |
| abaft | 15 10 | 15 0 | 13 0 | 10 6 | 9 8 | 11 0 | 9 0 |
| Number of tuns, tunage | 885 | 580 | 362 | ... | ... | 230 | 220 |
| Number of men (in warr) | 260 | 180 | 135 | 85 | 70 | 90 | 90 |
| Number of guns | 50 | 44 | 34 | 24 | 18 | 22 | 24 |
| Cube feet in the several draughts to their main water line | 29,814 | 22,346 | 13,105 | 8906 | 6790 | ... | ... |
| | Ts. ct. qr. lb. | Ts. ct. qr. lb. | Ts. ct. qr. lb. | Ts. ct. qr. lb. | Ts. ct. qr. lb. | Ts. | Ts. |
| Weight of each ship's hull, and all manner of materials on board | 851 16 2 8 | 638 9 0 19 | 377 0 0 3 | 254 9 0 16 | 194 0 0 0 | ... | ... |
| Each ship's hull at first launching | 416 0 0 0 | 314 0 0 0 | 180 0 0 0 | 120 0 0 [illegible] | 98 0 0 0 | ... | ... |
| Burthen in tuns, what she will really carry | 433 16 2 8 | 324 9 0 16 | 219 0 0 0 | 134 9 0 1[illegible] | ... | 135 | 130 |
| No. of months' provisions and water | 4 | 3 | 3 | 2 | 2 | ... | ... |

James II.

James II., from having so long and so gloriously filled the office of Lord High Admiral while Duke of York, was perfectly aware of the requirements of the navy; and during his short reign he paid great attention to increasing its efficiency. He also especially directed inquiries into the question of the durability of timber for the construction of it, and carefully accumulated both materials and stores for its maintenance. It is not a little curious that it was probably the attention which the monarchs of the line of Stuart had bestowed on the naval service, which enabled it so triumphantly to resist the persevering attempts of Louis XIV. to recover for them the throne of their ancestors.

The Revolution.

Though England was at the Revolution possessed of an efficient fleet, manned by experienced seamen, who had all the confidence arising from a series of naval triumphs, it must be remembered that for a long period no opposition to her naval superiority had been anticipated from any other power than Holland; and consequently the fleets of England were composed of ships which had many of them been built to adapt them to this service, for which small dimensions and light draughts of water were essential qualifications, on account of the shoalness of the Dutch coast.

William III.

William was too cautious a monarch to have neglected so important a means of national defence, as was the navy when engaged with such an ambitious and energetic opponent as Louis XIV.; and we find that the naval force was considerably increased, both numerically and in dimensions, during his reign. But the triumphs of our armies under Marlborough having for a time diverted the attention of the nation from naval affairs, it fell into decay during the reign of his successor.

Louis XIV.

When Louis XIV. determined to dispute with England for the sovereignty of the seas, he was not only without a navy, but without the means of forming one. The military and commercial marine of France had ceased to exist.

Rise of French naval power.

The sanguine temperament of the monarch, and the wisdom of his minister Colbert, removed all obstacles; commerce began to flourish on the quays, merchant-vessels to crowd the ports; dock-yards, harbours, and shipping appeared simultaneously to start into existence; and the nation, which almost for centuries had been essentially military, felt constrained to turn its energies to commerce and to the sea. A navy which in 1661 consisted of some four or five small vessels, in little more than ten years bearded and baffled the combined fleets of Holland and of Spain, and asserted the sovereignty of the Mediterranean. In 1681 her fleets consisted of 115 line-of-battle ships, manned by 36,440 men, with 179 smaller ships, the crews of which amounted to 3037 men; and in 1690 a fleet of eighty-four vessels of war, out of which three were of a hundred guns and upwards, and ten others were above eighty-four guns, with twenty-two fire-ships, was cruizing in the British seas. It is true that these mighty armaments failed in fulfilling the ambitious designs of Louis. But the severity of the struggle, which at length ended in the annihilation of his hopes, and in our triumphant assertion of our naval superiority, must always serve as an example of the danger we may incur by too great confidence in that superiority.

Comparison between English and French ships.

We have the following comparison between the French and British ships of about this period, from an official contemporary paper, by a gentleman of the name of Gibson: "Our guns being for the most part shorter, are made to carry more shott than a French gunn of like weight, therefore the French guns reach further, and ours make a bigger hole. By this the French has the advantage to fight at a distance, and wee yard-arm to yard-arm. The like advantage wee have over them in shipping; although they are broader and carry a better saile, our sides are thicker, and better able to receive their shott; by this they are more subject to be sunk by gunn shott than wee."

Injudicious management of royal navy.

The paper also complains much of the injudicious management of our shipping, by which it says, "many a fast sayling shipp have come to loose that property, by being over-masted, over-rigged, over-gunned (as the Constant Warwick, from twenty-six guns, and an incomparable sayler, to forty-six gunns and a slugg), over-manned (vide all the old shipps built in the parliament time now left), over-built (vide the Ruby and Assurance), and haveing great tafferills, gallarys, &c., to the making many formerly a stiff, now a tender-sided shipp, bringing thereby their head and tuck to lye too low in the water, and by it takeing away their former good property in steering, sayling, &c. The French by this defect of ours make warr with the sword (by sending no small shipps of warr to sea, but clean), and wee, by cruseing in fleetes, or single shipps foule, with bare threates."

Charnock's opinions and parallels.

Charnock draws some curious parallels between the state of the two navies of France and England during the earlier half of the eighteenth century, which may be summed up in a few words. That when the French took an English ship, it was seldom admitted into their navy; or, if admitted, it was only at a much lower rating, as, for instance, the Pembroke, a sixty-four in our service, became a fifty-gun ship in theirs. That in cases when an English fleet was in chase of a French fleet, it was ships which were British built which fell into our possession; but that almost on every occasion the French ships could evade ours. That the losses sustained in the French navy by foundering at sea, or by wrecks, were principally those ships which had been taken from us. That, on the contrary, the favourite ships in our fleets were those which had been taken from the French, and the instances in which French ships in our service were ever recovered possession of by them were extremely rare; we as far excelling them in all that related to the manœuvres and management of ships as they did us in designing them.

In consequence of the little attention bestowed upon the navy during the land-triumphs of Marlborough, it was found absolutely necessary, at the commencement of the reign of George I. that vigorous measures should be taken to re-establish it. Much pains were bestowed during this and the succeeding reign of George II. to improve its efficiency. The dimensions and the armament of the ships composing it underwent frequent revisals, and many valuable accessory improvements were made. Still it was evident that the perfect seamanship of the officers, and the undaunted valour of their crews, were frequently rendered nugatory by the superior qualities of the ships of their opponents, and the nation reaped little more than empty honour from the contests in which she engaged; the heavy sailers of England being unable to prevent her colonies and her commerce from suffering severely from the attacks of the light squadrons of her enemies. The naval commanders of England were constant in their complaints of the comparative inferiority in speed, in stability, and in readiness of manœuvring, of the ships under their command.

Lord Rodney.

In a letter from Sir George (afterwards Lord) Rodney, dated the 31st May 1780, to Mr Stephens, the secretary of the Admiralty, is a passage which proves in a remarkable degree the truth of the above statement. "Nothing could induce them (the French fleet), to risk a general action, though it was in their power daily. They made, at different times, motions which indicated a desire of engaging, but their resolution failed them when they drew near; and as they sailed far better than his majesty's fleet, they with ease could gain what distance they pleased to windward."

Cause of inferiority of English ships.

One great cause of the inferiority of our ships arose from the practice which prevailed during the first half of the eighteenth century, through a mistaken idea of economy, of "rebuilding" old ships, so that, in fact, the forms and dimensions of the previous century passed down in many instances nearly to the end of this; and, with little stretch of the imagination, we may suppose, that under a continuation of the same ill-judged system, we should have had the representations of the carracks and galleons of the reign of Elizabeth in the fleets of the present day!

**French system followed by Spain.**

The French system of improvement was followed by the Spaniards, and the capture of the Princessa in 1740, of seventy guns, 165 feet in length and forty-nine feet eight inches in breadth, when our ships of the same force then building were only 151 feet long and forty-three feet six inches broad, caused an appeal to be made by the Admiralty to Admiral Sir John Norris, the then "naval oracle" of England.

**Improvements attempted by the Admiralty.**

The consequence of the inquiries was, that the several master-shipwrights were directed to send in proposals for the future established dimensions of the navy; and in 1745 the Admiralty issued a new establishment for the dimensions of the several ratings of ships. The following table, taken from Derrick's Memoirs of the Royal Navy, contains the various established alterations from the reign of Charles II. to this of 1745, which was the last. Since then there has been considerable improvement, but there have been no fixed tables as established dimensions, at least none involving all the ratings.

The ships built after the establishment of 1745 are reported to have been stiff, and to have carried their guns well, but were still inferior to those of the French; and, consequently, about ten years afterwards an alteration was made in the draughts for the several ratings, and the dimensions were also slightly increased. It may not be uninteresting to remark, that the proportional breadths in the establishment of 1745 considerably exceeded those of more modern ships. Their breadth varied from $\frac{100}{349}$ to $\frac{100}{333}$ of their lengths; while, at the present time, with the exception of those built after the designs of the present surveyor of the navy, the breadths of most of our line-of-battle ships are within the limits of $\frac{100}{361}$ and $\frac{100}{383}$ of their lengths. We merely state this as a historical fact, not as advocating an undue increase of breadth. The question of the relative proportions of the dimensions of ships belongs to another portion of this article.

*An Account showing the Dimensions established, or proposed to be established, at different times, for Building of Ships. Extracted from Derrick's Memoirs of the Royal Navy.*

| | Establishment of | | | | | | | | Proposed in | | | | Establishment of 1745. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1677. | | 1691. | | 1706. | | 1719. | | 1733. | | 1741. | | | |
| **Ships of 100 Guns.** | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. |
| Length on the gun-deck | 165 | 0 | ... | | ... | | 174 | 0 | 174 | 0 | 175 | 0 | 176 | 0 |
| Length of the keel, for tonnage | 137 | 8 | ... | | ... | | 140 | 7 | 140 | 7 | 142 | 4 | 144 | 0¼ |
| Breadth, extreme | 46 | 0 | ... | | ... | | 50 | 0 | 50 | 0 | 50 | 0 | 51 | 8 |
| Depth in hold | 19 | 2 | ... | | ... | | 20 | 0 | 20 | 8 | 21 | 0 | 21 | 6 |
| Burthen in tons | 1550 | | ... | | ... | | 1869 | | 1869 | | 1892 | | 2000 | |
| **90.** | | | | | | | | | | | | | | |
| Length on the gun-deck | 158 | 0 | ... | | 162 | 0 | 164 | 0 | 166 | 0 | 168 | 0 | 170 | 0 |
| Length of the keel, for tonnage | ... | | ... | | 132 | 0 | 132 | 5 | 134 | 1 | 137 | 0 | 138 | 4 |
| Breadth, extreme | 44 | 0 | ... | | 47 | 0 | 47 | 2 | 47 | 9 | 48 | 0 | 48 | 6 |
| Depth in hold | 16 | 2 | ... | | 16 | 0 | 18 | 10 | 19 | 8 | 20 | 2 | 20 | 0 |
| Burthen in tons | 1307 | | ... | | 1551 | | 1566 | | 1623 | | 1679 | | 1730 | |
| **80.** | | | | | | | | | | | | | | |
| Length on the gun-deck | ... | | 150 | 0 | 156 | 0 | 158 | 0 | 158 | 0 | 161 | 0 | 165 | 0 |
| Length of the keel, for tonnage | ... | | ... | | 127 | 0 | 128 | 2 | 127 | 8 | 130 | 10 | 134 | 10¾ |
| Breadth, extreme | ... | | 41 | 0 | 43 | 0 | 44 | 6 | 45 | 5 | 48 | 0 | 47 | 0 |
| Depth in hold | ... | | 17 | 4 | 17 | 6 | 18 | 2 | 18 | 7 | 19 | 4 | 20 | 0 |
| Burthen in tons | ... | | 1100 | | 1283 | | 1350 | | 1400 | | 1472 | | 1585 | |
| **70.** | | | | | | | | | | | | | | |
| Length on the gun-deck | 150 | 0 | ... | | 150 | 0 | 151 | 0 | 151 | 0 | 154 | 0 | 160 | 0 |
| Length of the keel, for tonnage | ... | | ... | | 122 | 0 | 123 | 2 | 122 | 0 | 125 | 5 | 131 | 4 |
| Breadth, extreme | 39 | 8 | ... | | 41 | 0 | 41 | 0 | 43 | 5 | 44 | 0 | 45 | 0 |
| Depth in hold | 17 | 0 | ... | | 17 | 4 | 17 | 4 | 17 | 8 | 18 | 11 | 19 | 4 |
| Burthen in tons | 1013 | | ... | | 1069 | | 1128 | | 1224 | | 1291 | | 1414 | |
| **60.** | | | | | | | | | | | | | | |
| Length on the gun-deck | ... | | 144 | 0 | 144 | 0 | 144 | 0 | 144 | 0 | 147 | 0 | 150 | 0 |
| Length of the keel, for tonnage | ... | | ... | | 119 | 0 | 117 | 7 | 116 | 4 | 119 | 9 | 123 | 0½ |
| Breadth, extreme | ... | | 37 | 0 | 38 | 0 | 39 | 0 | 41 | 5 | 42 | 0 | 42 | 8 |
| Depth in hold | ... | | 15 | 6 | 15 | 8 | 16 | 5 | 16 | 11 | 18 | 1 | 18 | 0 |
| Burthen in tons | ... | | 900 | | 914 | | 951 | | 1068 | | 1123 | | 1181 | |
| **50.** | | | | | | | | | | | | | | |
| Length on the gun-deck | .. | | ... | | 130 | 0 | 134 | 0 | 134 | 0 | 140 | 0 | 144 | 0 |
| Length of the keel, for tonnage | ... | | ... | | 108 | 0 | 109 | 8 | 108 | 3 | 113 | 8 | 117 | 8½ |
| Breadth, extreme | ... | | ... | | 35 | 0 | 36 | 0 | 38 | 0 | 40 | 0 | 41 | 0 |
| Depth in hold | ... | | ... | | 14 | 0 | 15 | 2 | 15 | 9 | 17 | 2½ | 17 | 8 |
| Burthen in tons | ... | | ... | | 704 | | 755 | | 853 | | 968 | | 1052 | |
| **40.** | | | | | | | | | | | | | | |
| Length on the gun-deck | ... | | ... | | 118 | 0 | 124 | | 124 | 8 | 126 | 0 | 133 | 0 |
| Length of the keel, for tonnage | ... | | ... | | 87 | 0 | 101 | 8 | 100 | 3 | 102 | 6 | 106 | 10 |
| Breadth extreme | ... | | ... | | 32 | 0 | 33 | 2 | 35 | 8 | 36 | 0 | 37 | 6 |
| Depth in hold | ... | | ... | | 13 | 6 | 14 | 0 | 14 | 6 | 15 | 5½ | 18 | 0 |
| Burthen in tons | ... | | ... | | 531 | | 594 | | 678 | | 706 | | 814 | |
| **20.** | | | | | | | | | | | | | | |
| Length on the gun deck | ... | | ... | | ... | | 106 | 0 | 106 | 0 | 112 | 0 | 113 | 0 |
| Length of the keel, for tonnage | ... | | ... | | ... | | 87 | 9 | 85 | 0 | 91 | 6 | 93 | 4 |
| Breadth, extreme | ... | | ... | | ... | | 28 | 4 | 30 | 8 | 32 | 0 | 32 | 0 |
| Depth in hold | ... | | ... | | ... | | 8 | 2 | 8 | 5 | 11 | 0 | 11 | 0 |
| Burthen in tons | ... | | ... | | ... | | 374 | | 429 | | 498 | | 508 | |

**Royal George.**

The Royal George was the first ship built on the increased dimensions, which were the result of the before-mentioned inquiry. She was laid down in 1746, and launched in 1756; and rather more than ten years afterwards, that is, in 1758, History.

Triumph and Valiant.

the Triumph and Valiant of seventy-four guns were built on the lines of the Invincible, a French seventy-four-gun ship, captured in 1747.

We give the dimensions of these ships, as they were manifestations of an improved system, which, however, was not persevered in; for, with the exception of occasionally building after a French or Spanish model, the English ships were scarcely altered from those built at the commencement of the century.

| | Royal George. | Triumph and Valiant. |
|---|---|---|
| | Feet. In. | Feet. In. |
| Length on the gun-deck.......... | 178 0 | 171 3 |
| Length of the keel, for tonnage... | 143 5½ | 138 8 |
| Breadth, extreme.................... | 51 9½ | 49 9 |
| Depth in hold.......................... | 21 6 | 21 3 |
| Burthen in tons....................... | 2047 | 1826 |

Grand distinction between English and foreign navies.

There was still a very essential distinction between the navy of England and that of either France or Spain, which was this; that until after 1763 neither of these nations had any three-deckers in their fleets. Their largest armament appears to have been eighty-four guns on two decks, while we had third-rates which were three-deckers, as the Cambridge and Princess Amelia, launched in 1754 and 1757, and carrying only eighty-four guns. The capture of the Foudroyant, a French eighty-four on two decks, in 1758, caused a change in this respect, by furnishing the English with a model for a very superior class of men-of-war, which was adopted. Derrick, in his Memoirs of the Royal Navy, says, that "no eighty-gun ship with three decks was built after the year 1757, no seventy-gun ship after 1766, nor any sixty-gun ship after 1759."

French-built three-deckers.

During the peace that preceded the war with America, which commenced in the year 1768, the French had introduced three-deckers into their fleets, having found their eighty-fours on two decks to be no match for the more powerful of our three-deckers. Their first-rates were at this time generally of a hundred and ten guns on three decks. The Bretagne, one of these ships, was, according to Charnock, a hundred and ninety-six feet three inches long on the water line; and her moulded breadth was fifty-three feet four inches. Her displacement, it is stated in Sewell's Collection of Papers on Naval Architecture, was 4640 English tons.

Establishment of French fleets.

In 1786 the establishment of the French fleet was fixed by an ordinance, as according to the following table, which we extract from Charnock.

| | Ships of 120 Guns. | Ships of 110 Guns. | Ships of 80 Guns. | Ships of 74 Guns. | Ships of 64 Guns. | Frigates carrying 18 Pounders. | Frigates carrying 12 Pounders. | Corvettes of 20 Guns. | Advice-boats, carrying four 4 Pounders. |
|---|---|---|---|---|---|---|---|---|---|
| | Feet. In. | Feet. | Feet. | Feet. In. | Feet. In. | Feet. In. | Feet. In. | Feet. In. | Feet. In. |
| Length from head to stern...... | 196 6 | 186—185 | 184—180 | 170 0 | 156 0 | 144 0 | 136 0 | 112 0 | 80 0 |
| Breadth from outside to outside of the frame............ | 50 0 | 49 6 in. | 48 0 in. | 44 6 | 41 0 | 36 6 | 34 6 | 28 4 | 24 0 |
| Depth in hold.......................... | 26 0 | 24 6 | 23 9 | 22 0 | 20 0 | 18 0 | 17 6 | 14 4 | 12 0 |
| Draught of water abaft when light................................. | 17 6 | 17 4 | 17 0 | 15 8 | 14 6 | 12 6 | 11 3 | 9 6 | 8 4 |
| Draught of water forward when light........................ | 14 0 | 13 8 | 12 9 | 10 10 | 11 1 | 8 7 | 8 6 | 8 6 | 8 0 |
| Draught of water abaft when laden................................ | 25 0 | 24 8 | 22 6 | 21 6 | 19 9 | 16 0 | 15 4 | 13 3 | 11 6 |
| Draught of water forward when laden..................... | 22 8 | 22 2 | 21 0 | 19 10 | 18 9 | 15 2 | 13 9 | 11 9 | 10 0 |
| Total weight of the ship and stores when victualled and furnished for a six months' cruise................................ | Tons. 5246 | Tons. 4910 | Tons. 3825 | Tons. 3548½ | Tons. 2300 | Tons. 1479 | Tons. 1162 | Tons. 546 | Tons. 266 |
| Weight of the hull and masts... | 2500 | 2400 | 1804 | 1437 | 1129 | 665 | 583 | 266 | 141 |

George III. and George IV.

The ships of England continued throughout the wars of the reigns of George III. and George IV. notoriously inferior to those of France and Spain. The skill of our commanders, and the indomitable courage of our seamen, eventually succeeded in these, as in all former contests, in annihilating opposition, and in triumphantly asserting our naval supremacy. It cannot be denied that their task would have been comparatively easy, accompanied with less loss of life and expenditure of treasure, had their ships been more upon a par with those of their opponents.

Reasons for the continued inferiority of British shipping.

Although so much attention appears to have been directed at various times to the improvement of the navy, not only by the servants of the crown officially connected with it, but by the sovereigns themselves, we have seen that this continued inferiority of our ships to those of our opponents has been repeatedly asserted on undoubted testimony. The reason that all the attention thus bestowed failed in producing a corresponding beneficial effect was simply this; that in England the speculative ideas of men, undoubtedly of sense and judgment, as may be seen from the quotations of their opinions which we have made, but men uninformed as to principles, were taken as the rules for guidance. In France, on the contrary, the aid of science was called in, and some of the greatest mathematicians of the time turned their attention to the improvement of the shipping of that country; and it is a most astonishing fact, that the experience of more than a century of acknowledged inferiority to France, also with the admission that her superiority was caused by the researches of her mathematicians, should have still left it a question in England, whether our ships shall be designed on speculative opinions, or from scientific deductions. Colbert employed an engineer of the name of Rénau d'Elisagaray, a protégé of the Count de Vermandois, whose first essay was in the adaptation of ships to carry bombs, to be used in the then projected armament against the piratical states of the Mediterranean. Under the enlightened direction of Colbert, the French ships, which, by the ordinance of 1688, were much restricted in dimensions, were increased nearly one fourth in size, and every means taken which the then state of knowledge could suggest to insure a corresponding increase in good qualities. Rénau was, we believe, the first French author who wrote on the theory of ships. He was followed by the Bernoullis, by Père La Hoste, by Bouguer, Euler, Don Jorje Juan, Romme, and a host of others, the effects of whose writings we have traced in the progress of the improvements they introduced into the navies of France and Spain, and forced the navy of England to imitate. The only English treatise on ship-building that can lay any claim to a scientific character was published by Mungo Murray in 1754; and he, though his conduct was irreproachable, lived and died a working shipwright in Deptford dock-yard.

Instance of ignorance.

A most palpable instance of the ignorance of all the principles of naval architecture among the authorities who were charged with designing our royal navy, even up to the close of the last century, may be quoted from an article in a recent periodical publication, the Papers on Naval Architecture, which was devoted to the advancement of this science, and which was for some years conducted by two gentlemen who were educated at the School of Naval Architecture at Portsmouth. The article in question was written by Mr Wilson of the late Navy Office, now Admiralty, a gentleman whose judgment, talents, and sound professional knowledge as a naval architect, contrasted with the humbleness of his situation, that of draughtsman to the surveyor of the navy, may also be cited as affording an instance of the mistaken policy of the successive naval administrations of England, as to the encouraging the application of science to naval architecture.

Razee of the Anson.

Mr Wilson, speaking of the cutting down of the Anson, a sixty-four-gun ship, to a frigate of thirty-eight guns, says, "she was cut down in the year 1794; and although in all other maritime states the science of naval construction was well understood, yet so culpably ignorant were the English constructors, that this operation, so well calculated, when properly conducted, to produce a good ship, was a complete failure. Seven feet of the upper part of the top-sides, together with a deck and guns, making about 160 tons, were removed, by which her stability was greatly increased; but, by a complete absurdity, the sails were reduced one sixth in area. In her first voyage the rolling was so excessive that she sprung several sets of top-masts. To mitigate this evil, in 1795 her masts and yards were increased to their original size; but as there was no decrease of ballast, she was still a very uneasy ship, and, as a necessary result, her wear and tear were excessive.

"Other sixty-fours were cut down, masted, and ballasted in exactly the same manner, and, it need scarcely be added, experienced similar misfortunes; and although they were improved by enlarging their masts and yards, they were still bad ships. Had their transformations been scientifically conducted, a class of frigates would have been continued in the navy, capable, from their size, of coping with the large American frigates; and thus the disasters we experienced in the late war, from the superior force of that nation, would, without doubt, have been not merely avoided, but turned into occurrences of a quite opposite character."

Society for the Improvement of Naval Architecture.

Several attempts have been made in England to alter this state of things, and to establish a system of scientific improvement in our ships. One was the formation of a Society, in 1791, for the Improvement of Naval Architecture, which numbered among its members the late sovereign, then Duke of Clarence, and many noblemen and gentlemen of rank, influence, and talent. This society arose out of the patriotic exertions of a bookseller of the name of Sewell, the proprietor of the European Magazine, who in an excursion to one of our seaports, heard such universal complaints as to the inferiority of the British ships compared with those to which they were opposed, that he devoted the covers of his magazine to correspondence on naval architecture, and gave a room in his house for discussion on the same subject, and for the reception of plans and models connected with it, which were always open to public inspection. The papers that were by these means collected were republished in two volumes; and, among much trash, there are several valuable articles contained in them. The society conducted a course of experiments on resistances of fluids, in the Greenland docks, on which they appear to have exhausted their resources and their energies, and that too without deducing any results which added to the previous knowledge on that subject. We are not aware that more than the first year's Report of their proceedings was ever published. Of this we have only met with one copy; and in consequence of the probability that the results of the society's experiments might be completely lost, they were republished in the Papers on Naval Architecture. They have been since republished in a most splendid form, and in a most patriotic spirit, solely for gratuitous distribution to scientific societies and individuals, by Mr Beaufoy, the son of the late Colonel Beaufoy, the gentleman to whom the task of conducting them was intrusted by the society, and on whom, it appears, a great portion of the expenses devolved.

Colonel Beaufoy.

School of Naval Architecture.

Another effort to improve the scientific knowledge of naval architecture in this kingdom was the establishment, in 1811, of a School for Naval Architecture in her majesty's dock-yard at Portsmouth. This was in consequence of the statements and recommendations contained in the Report of a Commission of Naval Revision appointed in 1806. These recommendations were founded on an inquiry into the education and attainments of the shipwright officers then in the dock-yards, "from their first entry as apprentices, to their elevation to the rank of surveyor of the navy." The Report stated as follows:—"In the whole course we have described, no opportunity will be found of acquiring even the common education given to men of their rank in life; and they rise to the complete direction of the construction of the ships on which the safety of the empire depends, without any care or provision having been taken, on the part of the public, that they should have any instruction in mathematics, mechanics, or in the science or theory of marine architecture."

Report of the Commission of Naval Revision.

The Report stated it to be among the most important parts of the duty of the Commission to endeavour "to put an end to that want of foresight and due consideration, which may finally lead to so much danger to the country; and to bring into our dock-yards apprentices of more liberal education than has hitherto been required."

School of Naval Architecture established.

The Commissioners recommended the establishment of two classes of apprentices. They proposed the arrangments necessary for putting their recommendations into practice, and also laid down a system of education for the first class. These proposals were directed to be carried into effect, by an order in Council of the 20th of September 1809, which was complied with in the establishment of the School of Naval Architecture on the first of January 1811.

The arrangements of the school were modified by a second order in Council on the 20th of January 1816, in consequence of a building for the reception of the students having been completed. By this order the establishment was incorporated with the Royal Naval College, and the number of students limited to twenty-four, that number being considered as "sufficient to supply the place of officers who may die or be removed," and therefore to fulfil the intentions of the Board of Naval Revision. This second order in Council stated, that the object of the institution was to introduce "a better and more skilful description of shipwright officers in his majesty's royal dock-yards;" and the "regulations established relative to the admission of students into the School of Naval Architecture," for the information of the candidates, stated that, "on the expiration of the apprenticeship, the students will be eligible to all situations in the ship-building department of his majesty's service; and in the event of there being no vacancy in any of his majesty's yards, they shall be employed as supernumeraries in the yards, until vacancies do occur," "provided the apprentice shall, at the expiration of the time above mentioned, have completed the plan of education, and shall be certified by the professor to be properly qualified."

Number of students.

Forty-two gentlemen have been educated at this establishment, and twenty-two still remain in the ship-building department of her majesty's service, of whom many, bound to the service under heavy penalties, were, for eight or ten years after leaving the school, employed as supernumeraries in the dock-yards, awaiting their first appointments as foremen, although vacancies were during the interval continually occurring. Three only have been promoted to the step next above that of foreman; and, out of the last fourteen appointments to situations superior to that of foreman, only one has been conferred upon a member of the School of Naval Architecture.

The attempt has therefore most signally failed. For, from the comparative ages of the gentlemen of this establishment, and those of the officers who have been placed in these vacancies, there can be no rational hope that the expectations of the Commissioners of Naval Revision, or of the members of the Councils of State, can be fulfilled; and it may therefore now be said (in 1839), with as much truth as by the Report of the Board of Naval Revision in 1806, "nothing certainly can be more surprising than that, in a nation so enlightened as this is, and whose power, importance, and even safety, depend on its naval superiority, matters so essential to the preservation of that superiority should so long have been neglected."

Abolition of the school.

Reasons of its failure.

The School of Naval Architecture was abolished in 1832; and we cannot write of the failure of this establishment without endeavouring to trace its causes, and to account for the strong prejudice which has existed against its members from the moment the first student's name was recorded on its books; a prejudice which has baffled them in every endeavour to obtain just attention to their claims from each successive naval administration, and which has virtually deprived the nation of the advantages anticipated by the Board of Naval Revision. That it is not in the failure of the students themselves to fulfil the conditions required of them, is evident, since the sole condition was that which we have quoted from the regulations, that they should complete the plan of education, "and be certified by the professor to be properly qualified." This the professor has officially complied with in the strongest terms. Nor is it that they are individually unfit to fill the situations which were guaranteed to them; for many of them are possessed of the most flattering testimonials of efficiency, as thorough practical officers, men of business, and gentlemen of principle. We believe it to arise solely from this, that the foundation of the establishment was accompanied by the most mortifying and humiliating reflections on the officers then filling the situations in the dock-yards, and, consequently, on all who rose to such situations from the working class of the yards. From these officers, to all of whom the very existence of the School of Naval Architecture has been a reproach, and a constant source of mortification, and to many of whom the advance of its members would operate as a bar to promotion, successive Admiralties have been contented to derive their information as to the success of that establishment, and the efficiency of its members. It surely would be expecting more than can be hoped from human nature in its most exalted state, to suppose such information could be given devoid of party feeling and of prejudice, or that men would voluntarily admit their own inefficiency, and concede to those whom they must regard as their rivals for the favours of the Admiralty, a merit equal, nay, on the very principle of the foundation of the establishment, superior, to that which they themselves possess. The First Lord of the Admiralty, therefore, for the time being, acting on information thus derived, annually asserts in his place in parliament, and believes his assertion to be correct, that these "young men" (men between forty and fifty years of age) "though gentlemen and men of education, yet want experience, and therefore cannot be promoted."

It has been productive of much good.

The institution has however not been unattended with benefit to the service. The correct principles of naval architecture have become known and generally diffused; and though the members of the establishment may not reap the reward, the merit is undoubtedly theirs, for it has been through their instrumentality and from their works. It cannot, either, be denied that the officers of the dock-yards of the old school have had their energies aroused, and have risen in the scale of educated society, from their rivalry with the members of the new. On an inquiry into their competency to fill the situations in which they have been placed, though there would be many instances fully to warrant as great animadversion as was passed by the Board of Revision on their predecessors, there would also be found among them gentlemen, men of talent, and of considerable acquirements.

Sir William Symonds.

In 1830, Captain, now Sir William Symonds, was appointed to the office of surveyor of the navy, he having previously constructed a corvette, the Columbine, for her majesty's service, which was reported most favourably of after a trial cruize with other corvettes built from designs furnished by Sir Robert Seppings and the late Admiral Hayes.

The appointment of a naval officer to fill the solitary situation in the civil service of the navy which may be said to offer any great inducement to the exertions of the naval architect, was certainly to be lamented. There are few clerks in the public offices of this country who do not early attain to salaries and retirements far exceeding those doled out to the highest offices in the engineering department of the navy, with this one exception; and to deprive the naval architect of this high incitement to exertion, cannot but operate injuriously to the service; and again, a gentleman brought up in a totally different profession must be presumed to be not only wholly unacquainted with the detail of the duties of his subordinates, but also necessarily to be unqualified to perform a great portion of the duties connected with his own situation, and therefore to be dependent upon those from whom he is obliged to seek for guidance.

The office of surveyor of the navy, be it remembered, is an office of active operation rather than an office of supervision, and therefore essentially requires to be filled by a professional naval architect.

Sir William Symonds is the first constructor of the English navy who has been left unrestricted as to dimensions; and he has consequently been enabled to introduce into the service, ships which undoubtedly bear very high characters in some very decided points of efficiency as men-of-war. He has also practically demonstrated the possibility of ships of war obtaining sufficient stability without the aid of ballast, which is a very important advantage, and one which will yet be productive of essential benefit. But unfortunately having been in error as to the true principles on which the stability of floating bodies is dependent, he has not obtained these advantages without, in many instances, incurring a compensating disadvantage, from uneasiness of motion, and which appears to be a very general complaint against the ships of his construction, some of them being most marked examples of the uneasiness attendant on a stability which depends almost wholly on breadth at the load water-section, to the neglect of the form of the solids of immersion and emersion.

His writings.

The opinions on which Sir William Symonds founds his system of construction have been explained by him, first in a brochure, printed, we believe, for private distribution, and then in an article, communicated by himself, in the United Service Journal for July 1832. To that therefore we refer our readers for information as to the principles upon which the fleets of England are now constructed. The following tables contain the dimensions of the various classes of ships which Sir William Symonds has introduced into the British navy; also the dimensions according to which the ships of the French navy are now being built, and the dimensions of one or two other modern ships about which considerable interest has been excited. The dimensions of the vessels designed by Sir William Symonds are obtained from Edye's Scales of Displacements, and from a list which was published in the United Service Gazette, and which we have endeavoured to verify; we therefore believe them to be correct. The dimensions of the French ships were procured in the French dock-yards during the summer of 1837, and are certainly correct. The London and Castor are obtained from Edye's Scales of Displacements; the Sapphire and Orestes from Morgan and Creuze's Papers on Naval Architecture; and the other dimensions are from the best available authorities.

*Dimensions of Modern English Ships of War.*

| Names of Ships, and of their Designers. | Guns. | Length of Gun-Deck. |  | Length of Keel for Tonnage. |  | Extreme Breadth. |  | Depth in Hold. |  | Burden in Tons. |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. |  |
| Designs of Sir William Symonds. |  |  |  |  |  |  |  |  |  |  |
| First Rate. |  |  |  |  |  |  |  |  |  |  |
| Queen | 110 on 3 decks | 204 | 0 | 166 | 5 | 60 | 0 | 23 | 9 | 3099 |
| Second Rate. |  |  |  |  |  |  |  |  |  |  |
| Vanguard | 80 on 2 decks. | 190 | 0 | 155 | 3 | 56 | 9 | 23 | 4 | 2589 |
| Third Rate. |  |  |  |  |  |  |  |  |  |  |
| Boscawen | 70 on 2 decks. | 180 | 0 | 146 | 8 | 54 | 0 | 22 | 4 | 2212 |
| Fourth Rate. |  |  |  |  |  |  |  |  |  |  |
| Vernon | 50 | 176 | 0 | 144 | 6¼ | 52 | 8¼ | 17 | 1 | 2082 |
| Fifth Rate. |  |  |  |  |  |  |  |  |  |  |
| Pique | 36 | 160 | 0 | 131 | 0 | 48 | 8 | 14 | 6 | 1622 |
| Sixth Rate. |  |  |  |  |  |  |  |  |  |  |
| Vestal | 26 | 130 | 0 | 105 | 9 | 40 | 7½ | 10 | 6 | 913 |
| Carysfort | 26 | 130 | 0 | 106 | 10 | 40 | 0 | 10 | 6 | 911 |
| Corvettes. |  |  |  |  |  |  |  |  |  |  |
| Rover | 18 | 113 | 0 | 90 | 1¾ | 35 | 5 | 16 | 9 | 590 |
| Calypso | 18 | 120 | 0 | 99 | 5¾ | 37 | 6 | 18 | 0 | 731 |
| Brigs. |  |  |  |  |  |  |  |  |  |  |
| Columbine | 16 | 105 | 0½ | 84 | 0 | 33 | 6¼ | 7 | 11 | 492 |
| Serpent | 16 | 102 | 5 | 79 | 10 | 32 | 3 | 15 | 0 | 434 |
| Racer | 16 | 100 | 8 | 78 | 9½ | 32 | 4¾ | 14 | 10 | 431 |
| Pantaloon | 16 | 91 | 10 | 71 | 4 | 29 | 4 | 12 | 8 | 323 |
| London } Sir Robert Seppings | 92 on 2 decks. | 205 | 6 | 170 | 4 | 54 | 4 | 23 | 2 | 2598 |
| Castor } Sir Robert Seppings | 36 | 159 | 0 | 133 | 7 | 43 | 0 | 13 | 6 | 1283 |
| Inconstant, Admiral Hayes | 36 | 166 | 6 | 133 | 5⅝ | 45 | 5 | 13 | 7 | 1422 |
| Modeste, Admiral Hon. G. Elliot | 18 | 120 | 0 | 98 | 7 | 32 | 9 | 7 | 11 | 562 |
| Sapphire } Professor Inman | 28 | 119 | 0 | 100 | 7½ | 33 | 8 | 8 | 0 | 605 |
| Orestes } Professor Inman | 18 | 109 | 11 | 92 | 10⅝ | 30 | 6 | 7 | 6 | 459 |

*Dimensions of Modern French Ships of War.*

|  | Line-of-Battle. |  |  |  |  |  | Frigates. |  |  |  | Corvettes. |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Guns | 120 |  | 100 |  | 90 |  | 60 |  | 52 |  | 32 |  | 24 |  |
|  | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. | Feet. | Inch. |
| Length on gun-deck between rabbets | 209 | 5 | 205 | 0½ | 198 | 6 | 178 | 1½ | 172 | 1 | 138 | 7½ | 125 | 4 |
| Moulded breadth | 55 | 3¾ | 54 | 11½ | 53 | 5¾ | 47 | 7 | 45 | 2½ | 36 | 0¼ | 32 | 7¼ |
| Draught of water, forward | 24 | 11¾ | 23 | 10¾ | 23 | 4 | 19 | 11½ | ... |  | 14 | 9 | 13 | 6½ |
| Draught of water, aft | 26 | 8¾ | 26 | 0½ | 25 | 4 | 21 | 3¼ | ... |  | 16 | 3 | 14 | 10 |
| Draught of water, mean | 25 | 10¼ | 24 | 11½ | 24 | 4 | 20 | 7½ | 20 | 8 | 15 | 6 | 14 | 2¼ |
| Load, displacement in tons | 4940 |  | 4393 |  | 4013 |  | 2542 |  | 2267 |  | 999 |  | 738 |  |

*Description of the manner of performing the Calculations incidental to designing a Ship, with Investigations of some of the principal Elements of the Design.*

Few principles of the theory of ships now remain uninvestigated.

The labours of the numerous men of science who have devoted either the whole or a portion of their attention to the various problems embraced in the theory of ships, have left but few of its abstract principles uninvestigated; most of the properties of a ship have been examined, and the laws on which they depend clearly defined, either by the aid of mathematical demonstration, or by experimental induction. There are however some questions, which, though solved in theory, still depend on the results of physical experiment for perfecting their practical application.

Elementary principles may be classed in two divisions.

The elements of naval construction, a term very generally applied to the theory of ships, may be classed in two divisions; those which are solely dependent on known laws of nature, and those of which the solution involves laws of nature which are yet imperfectly developed.

The first division embraces by far the greater part of those principles on which the most essential properties of ships depend; and it may now be said that the principal difficulties of these are surmounted, and are familiar to the instructed naval architect. These are alone sufficient to insure the attainment of a certain and considerable degree of excellency in a ship, to give it a preponderance of any peculiar property, to discover the causes of any bad quality, and to obviate its tendency by an appropriate remedy. In fact, they are enough, quoting from an article in an American Review, to "direct and limit the variations that may safely be made in the models at present in use, and guide us in the draught of new ones, suited to those changes in the force and magnitude of the several rates of vessels, which are continually making in the strife between the nations of the civilized world." Should the science of naval architecture never make further progress than it is thus described as having attained, it is evident that it is so far perfect as to be available for, and capable of being made to keep pace with, the wants of mankind. It may be objected, that the American writer assumes too high a standard, and that, so far from changes in the rate and magnitude of ships being made with the certainty attributed, each deviation from the beaten track seems but an isolated, baseless, and aimless venture, instead of forming one step in the progress of improvement. But, in justice to naval architecture, it should be remembered that the American spoke of the existing knowledge, and of the application of that knowledge in France, and in countries where its importance is recognised and its principles are known and cultivated, not in England, where its very claim to the rank of a science has been derided.

Of one the principles are established.

Practice apparently contradicts this assertion.

Second division embraces elements dependent on undeveloped laws of nature.

The elements which may be classed in the second division, as those of which the solution resolves itself into a dependence on laws of nature which are as yet imperfectly developed, consist almost entirely of such as are dependent, in a greater or less degree, on a knowledge of the nature and laws of elastic and non-elastic fluids. This is a subject which has hitherto baffled alike the researches of the mathematician and the experimentalist; but, from the analogy of discoveries in other sciences, we may safely assert, that even its difficulties must be eventually surmounted by the patience and labour of the inductive philosopher. We are possibly on the eve of an important era, in so far as the laws of the resistances of fluids are involved. The researches of Mr Russel will apparently do much towards unravelling their mysteries, perhaps more than has as yet resulted from the labour of all preceding ages. Not that the perfect solution of these problems is really of such vital importance to the progress of improvement in naval architecture as it is often asserted to be, and which the apparent intimate connection of that science with the knowledge of fluids and of their laws would appear to sanction. Of those elements of naval construction which seem wholly to depend on such knowledge, some are restricted by considerations which are adverse to its application; and although it may be a desideratum in the determination of certain of the elements, the difficulties which arise from the want of it only require to be fully known and understood, to be, if not absolutely theoretically removed, at least, from the collection of facts, from experiment, and from analogy, so far overcome as to leave nothing to be desired on the score of practical utility. The form of a ship's body need not necessarily remain imperfect because the curve of the solid of least resistance is unknown, since enough has resulted from the consideration of the nature of that solid to prove that, however it might probably be applicable to the navigation of smooth waters, the perfect solution of the problem of its form could only be generally desirable to the naval architect, as contributing to the theoretic perfection of the science, and would add but little to its practical utility in its application to vessels which must encounter the tremendous powers of the elements in the open seas. Experience has proved, that a ship constructed with the bow and of the form which are recognised as at least nearly approximating to the solid of least resistance, would be unable to withstand the violence of the shocks of the motion of pitching, and of the waves; or, could she do so, would necessarily lose, by the additional resistance resulting from increased immersion, every advantage which might otherwise be anticipated. Neither can the exact position of the greatest section be a question of theoretic niceties, when the great capacity and the adjustments of form necessary to the exigencies of modern warfare and the advanced state of navigation are considered, which not only require a ship to be effective in all the *matériel*, and for all the purposes of war, when first from the hands of the builder, but to be equally so after long periods have elapsed and extended seas have been navigated. On the other hand, the comparative fulness of the fore and after bodies, the positions, rakes, and proportions of the masts, the adjustment and the shape of the sails, the bracing of the yards, and many other questions intimately connected with the resistance of fluids, may, and will eventually, be correctly determined by comparison, experiment, and induction, guided by the knowledge of those principles of science which are involved in them; and, without such knowledge to enable us to test and to establish the correctness of the conclusions which may be drawn, both experiment and comparison must be as useless in this, as, under similar circumstances, they would prove to any other branch of art. It has been most wisely said, that there are more false facts in the world than false theories. The reason is evident; the correctness of a fact is totally dependent on the competency of the observer; and how very few, even among those whose minds have been trained to habits of thought, are competent to the task of discriminating fact from fallacy. If there be few among such men, how much fewer in proportion must that number be among men of uncultivated minds, who can be capable either of observing facts, or of forming correct conclusions from those which they may have casually observed; and to such, almost without exception, has been confided the task of establishing the facts, and drawing the conclusions, upon which to found the theory of ships, as far as the development of that theory has been attempted in England.

Mr Russel's researches on resistances.

Such knowledge not indispensable to the naval architect.

Proportions of the body, the positions and rake of masts, proportion and shape of sails, may be determined by induction.

Danger of erroneous deductions, unless made with aid of scientific knowledge.

A most unphilosophic mode of reasoning is very generally applied to the question of the application of the exact sciences to naval architecture; and because chance on some few occasions, inductions from a tedious experience of failures on others, but far more frequently the results of observations on ships built by men of science, may have produced good ships, the question is often hastily decided, and the conclusion assumed, that since ships possessing more than an average of good qualities have been produced without abstract scientific study, therefore the exact sciences cannot be available to the advancement of naval architecture; the fact being placed quite out of the consideration, that the results of observations on ships designed by men of science are really the results of science, and that if the observations were made by persons competent to the task, these results would be onward steps in the progress of improvement.

Error in doing this.

How it has arisen.

The time certainly has not yet arrived when the naval architect can effect with precision and confidence the synthetical composition of a perfect ship; but we have already asserted that he may, by the application of principles already established, proceed in the full confidence of producing one with a preponderance of good qualities.

The aid of induction cannot yet be dispensed with;

The mistake is in the assumption that the theory of ships is already perfected, instead of merely being capable of being perfected by a rigid analysis of facts which daily experience would elicit were the abstract sciences applied to the task of analysing, collating, and registering them. It should always be remembered, that generally in every science a

for the theory of ships is yet imperfect.

perfect theory is the result of the perfection of the science, rather than that the perfection of the science results from the theory. To argue against this principle, would be to retrograde from the nineteenth to the sixteenth century, and to affirm that Bacon has lived in vain.

We shall, in as concise a manner as is consistent with clearness of explanation, detail the method of performing the calculations necessary to determine the essential elements of the design of a ship's body, in the course of preparing the original draught or drawing.

A body at rest on a fluid displaces its weight.

A body floating at rest, upon a fluid also at rest, displaces as much of the fluid as is equal to the weight of the body. The truth of this proposition will appear from the consideration that the equilibrium between the body and the fluid is maintained by precisely the same upward pressure as supported the fluid which the body has displaced; and as the same pressure must support the same weight when there is an equilibrium, the weight of the floating body must be equal to that of a quantity of fluid equal in bulk to that part of the body which is immersed. It follows that the weight of the water displaced by a ship floating on it at rest, is equal to the weight of the ship and all its contents.

Displacement synonymous with the weight.

It is usual to call the weight of the quantity of water which a ship displaces when she is floating at rest, her displacement; or, in other words, according to the foregoing proposition, the term displacement applied to a ship is synonymous with her weight.

To obtain the weight of a ship.

To obtain, therefore, the total weight of a ship, it is only necessary to ascertain the weight of the volume of water which she displaces when floating at rest. This is found by calculating the number of cubic feet contained in a homogeneous solid equal in bulk to that part of the body below the surface of the water, and then multiplying this number by the specific gravity of the water, that is, by the weight of one cubic foot: the result will be the weight of the water displaced, and consequently also that of the ship.

First guide to dimensions.

Greatest transverse section.

Greatest horizontal section.

Depth in water, and difference of draught of water.

Bow and quarter sections.

That a ship of war may be able to carry and to maintain effective, in ordinary circumstances of weather, a determined armament, or a merchant-ship a certain lading, it is evident that the weight of the ship, and all that she is destined to contain, must be in such proportion to her bulk that she shall not be so far immersed in the water as to render her armament inefficient under circumstances in which its efficiency may be required; or her lading oppressive to her, if lading be the purport of her construction. The bulk of a ship is in proportion to her length, her breadth, and her depth. This, when the naval architect has ascertained the displacement necessary for his ship to possess, is his first guide to proportion her dimensions, so as to insure that displacement without undue immersion. The next step is to determine the form and area of a transverse vertical section at the largest part of the ship's body, which generally extends from the middle of the length for some distance towards each extremity. This section is called the midship section, and on its area is principally dependent the direct resistance which the vessel will experience, while the stability or resistance to inclination, and the easiness or uneasiness of her motions, are greatly dependent on its form. Having to a certain extent fixed upon the midship section, the next consideration is to determine the area and form of a horizontal section at the surface of the water. This section is called the load water-section, or sometimes the "plane of flotation." On this section also the stability of the ship, in proportion to her dimensions, is very greatly dependent, as will be seen when we more fully explain that quality. The depth in the water, and the shape of the vertical section through the longitudinal axis of the ship, should next be determined; and then transverse vertical sections of the body between the midship section and either extremity of the vessel, generally at those parts where the body is intended to alter materially from the form of its midship section to that of the more sudden curvature at the extremities. An important consideration is involved in the forms of these sections, considerably influencing the easiness of the ship's motions. At present it will be enough to mention them as the next progressive step in the design;

Displacement.

after which the constructor has data sufficient to determine whether the dimensions he has chosen will enable him to obtain adequate displacement for the services required of his vessel. If so, he may proceed to trace in intermediate sections, and thus gradually, letting his design keep pace with his calculations, complete his drawing by the aid of processes which will be fully explained in a subsequent portion of this article, and which we therefore shall wholly omit here, as the limits of our space will not admit of repetition. Also, we can hardly describe the method of proceeding with the drawing until the principles which ought to guide us in forming the design have been investigated.

Diagonal, bow, and buttock lines. Inclined water-lines.

As we are totally unacquainted with the course of the fluid along the bottom of a vessel, it is essential that the curves bounding diagonal sections, called diagonal lines, and the curves bounding vertical sections, called buttock and bow lines, should be attentively considered, and also the curves bounding the inclined water-sections, that they may be such as, by comparison with other and acknowledged fast ships, may be presumed to be conducive to velocity. It must constantly be remembered, that naval architecture is a science of comparisons and of analogies; and no pains must be spared in rendering them subservient, not only to the design in progress, but to the eventual perfection of the science.

Alteration of seat in water from consumption of stores.

An important consideration connected with the forming the design of a ship is involved in the gradual alteration of the vessel's seat in the water from the consumption of stores. It is not only essential that a ship should be possessed of stability combined with easiness of motion, be weatherly and quick in manœuvring when she is stored and completed for foreign service as a ship of war, or fully laden as a merchant-ship; but it is equally essential that she should be possessed of these qualities towards the expiration of her cruize, or on her return light from her voyage. Designs for ships to be as perfect as the present state of knowledge can make them, must be made with reference to several water-lines.

Merchant-ships more uncertain in qualities than ships of war,

We see, therefore, that there are difficulties opposed to the improvement of the forms of merchant-ships, which do not exist to the same extent in opposition to the improvement of the forms of ships of war.

because of greater variation of seat in water.

In the designing of ships of war, the nature of the service in which they will be employed is known, and the lading, in comparison with that of a merchant-ship, is a constant quantity: it is therefore only necessary to endeavour to obtain a maximum of good qualities in relation to these circumstances. But in a merchant-ship the lading is of such a variable nature, both as to quantity and species, that the ship is at different times under very different circumstances; yet she is subjected to the same trials. Thus an East Indiaman, on her outward voyage, is two feet more immersed than on her homeward; and the draught of water of a collier is reduced, at different times, four, five, or six feet, by which the stability is generally very much diminished; and even with the same draught of water the stability may vary very considerably, owing to the difference in the nature and disposition of the lading, and the consequent effect produced on the centre of gravity of the ship; and yet, under these different circumstances, the ships are exposed to the same winds and seas. It is evident that if, when at their proper draught of water and stowage, they are only equal to the trials to which they are subject, they must be very inadequate to the contest with such a deduction from their powers as this would produce; particularly if their design be not made with a due consideration of this circumstance.

The loss of stability which results from the diminution of draught of water cannot be compensated by a proportionate arrangement of sail, without incurring other evil consequences. If the quantity of sail, which at all times is comparatively small in a merchant-ship, be lessened, the wind on the increased hull might so counterbalance its effect, that she would be utterly unable to beat off a lee shore, or make any way on a wind.

causing diminution of stability, and increased uneasiness.

A ship is not only subject to a loss in stability when lightened, but becomes laboursome, on account of top-hamper: her rolling motion is more violent as her diminished depth in the water decreases the resistance which is opposed to the inclination, and she also generally becomes more leewardly, owing to the difference made in the resultant of the resistance, the diminution of the lateral resistance, and of her power of carrying sail.

That these effects are to be dreaded, is proved by the enormous loss of lives and property in light merchantmen, and especially light colliers.

Thus, for a ship which is intended for the various purposes of commerce, to be at all equal to a ship destined only to sail with a constant lading, more art is required in the design. But though this is a difficulty which opposes itself, it is no bar to progressive improvement, which is evident, as we are now suffering under the effects of such improvement, made, under all the same obstacles, by foreign powers.

Sacrifice of burthen necessary,

That the forms of merchant-ships may at all be benefited by the application of that knowledge which is possessed of the principles of naval architecture to their construction, a sacrifice in part must be made of those qualities which have hitherto been considered too exclusively at the expense of others. These are great capacity under small dimensions, and few men to navigate them.

by increased dimensions in proportion to displacement.

To enable them to sail and work well, their resistance must be diminished and their stability improved by an increase of dimensions in comparison with the displacement, by which they would gain in velocity, easiness of motion, power to carry sail, and consequently safety. But this would require a proportionally greater quantity of sail, and of course a larger crew to manage it; yet as other nations possess better ships than ourselves, and have therefore subjected themselves to this inconvenience of larger crews, that must not be considered as an insurmountable obstacle.

As the body of a ship is not generally any regular figure, the rules which determine the contents of regular solids will give only approximations when applied to finding its content; but the error arising from the application of the best methods now used for calculating displacements is so small as to be utterly insignificant in practice.

Atwood's rules for areas of curvilinear spaces.

The rules most applicable, and at present most generally applied, to the measuring of curvilinear spaces, by naval architects, are those published by Atwood in the Philosophical Transactions of the Royal Society for 1798. "They are founded on Sir Isaac Newton's discovery of a theorem, by which, from having given any number of points situated in the same plane, he could ascertain the equation to the curve which would pass through them all; and by means of this equation was enabled to express the ordinate in the curve corresponding to an abscissa of any given length, as well as the area intercepted between any two of the ordinates."

In order to determine the area of any curvilinear space by these rules, parabolic curves are supposed to pass through the extremities of a certain number of equidistant ordinates, dependent on the order of the parabola; for a conic parabola three ordinates, for a parabola of the third order four ordinates, and so on. It is evident that the correctness of the approximation of the parabolic area to the area of the required curvilinear space, is dependent on the distance between the ordinates; as on that depends the nearer or the more remote coincidence of the parabolic curve with the curve bounding the area required. An almost mathematical accuracy is attained in naval architectural calculations by assuming the ordinates to be one foot apart, even in those portions of the curvilinear areas in which the alterations of the ordinates are the most rapid, as in the fore, after, and lower parts of the body. But spaces considerably longer than this will be found to give results of great correctness.

Two only in use.

Atwood gives eight theorems for measuring curvilinear spaces, two only of which are necessary for the purposes of the naval architect.

First rule. Number of ordinates odd.

The first of these is applicable when the number of equidistant ordinates is odd. It is founded on the assumption, that each portion of the curve which passes through the extremities of three successive ordinates is a part of a conic parabola, and that the first of the three ordinates of each succeeding portion is the last of the three ordinates of the preceding portion. It is not necessary in this article to prove the correctness of these rules; it is sufficient to describe their application to the subject of the article.

The first rule is as follows: Measure the lengths of all the equidistant ordinates. Take the sum of the extreme ordinates, then take the sum of the second, fourth, sixth, or even ordinates, and multiply it by four; and then take the sum of the remaining odd ordinates, or the third, fifth, &c., and multiply it by two. To the sum of these two products add the sum of the extreme ordinates, and multiply this sum by one third of the common interval between the ordinates; the result will be the approximate area required.

Second rule. Number of ordinates exceeds by unity a multiple of 3.

The second rule, which is frequently useful, is applicable when the number of ordinates is one greater than a multiple of three. It is founded on the assumption that each portion of the curve which passes through the extremities of four successive ordinates is a part of a cubic parabola, and that the first of the four ordinates of each succeeding portion of the curve is the last of the four ordinates of the preceding portion.

This rule is as follows: Measure the lengths of all the equidistant ordinates. Take the sum of the extreme ordinates, then take the sum of those remaining ordinates which are one greater than a multiple of three, as the fourth, seventh, tenth, &c., and multiply it by two; and then take the sum of all the remaining ordinates, and multiply it by three. To the sum of these two products add the sum of the extreme ordinates, and multiply this sum by three eighths of the common interval between the ordinates; the result will be the approximate area required.

Their application to find the contents of solids.

Now, if we suppose that we have a solid formed by the revolution of a curve, and that the cubical content of that solid is required, we may first, by the application of either of the before-mentioned rules for obtaining the areas of curvilinear spaces, find the areas of a series of parallel and equidistant sections of the solid. Then, if we consider these areas as expressing ordinates to the abscissa of a curve, we shall have a curvilinear plane surface, the area of which will express the cubical contents of the solid. For it is evident that every increment of the assumed curvilinear area has correctly represented the contemporary increment of the solid.

We have here, then, rules of easy application, by which the areas either of the transverse vertical or the horizontal sections of a ship's body may be calculated, and by which also, from a series of the areas of either these vertical or these horizontal sections, the cubical content of a homogeneous solid, of the same shape and bulk as the immersed portion of the ship's body, may be determined; which cubical content, multiplied by the specific gravity of water, will give the displacement of the ship.

It will be seen, as we proceed with our subject, that it is necessary to ascertain the position of the centre of gravity of the homogeneous solid of the immersed part of the ship, and also, that in proceeding with the work of designing the form of a ship's body, it will be necessary, in order, in the earliest steps, to confine the position of this point to certain limits, to calculate the situations of the centres of gravity of the load water-section and of the midship section; that these points, which will necessarily have great influence on the position of the centre of gravity of the displacement, may be determined with reference to their influence on the position of that point. These calculations are effected by a further application of the rules of approximation already given.

Necessary to find the centre of gravity of the homogeneous solid of the immersed body, and of the load water and midship sections. Its position in the load water-section; in the midship section;

Every transverse ordinate of the load-water section being bisected at its intersection with the vertical longitudinal section passing through the stem and stern-post, the centre of gravity of the load water-section will necessarily be in the line of these intersections; it becomes therefore necessary only to find its position in this line. For the same reason, that of the bisection of the ordinates, the centre of gravity of the midship section will be in the line of its intersection with the vertical longitudinal section, passing through the stem and stern-post; and it becomes therefore only necessary to determine its position in this vertical line. And again, the centre of gravity of displacement must be always in the same before-mentioned vertical longitudinal section, unless the vessel be inclined from the upright, which consideration does not enter into the present question; it becomes therefore necessary to find its position in this section. In respect to length, this will be found in the line of intersection of some one of the transverse vertical sections with this vertical longitudinal section; and in respect to depth, in the line of intersection of some one of the horizontal sections with this same vertical longitudinal section; and, consequently, the position of this centre of gravity of the displacement, or, as some writers call it, the "centre of buoyancy," will be in the point of intersection of the three planes.

in the homogeneous solid.

General expression for centres of gravity.

In order to determine the positions of these several centres of gravity, we must make use of this proposition in mechanics. If perpendiculars be drawn from any number of bodies to a given plane, the sum of the products of each body, multiplied by its perpendicular distance from the plane, is equal to the product of the sum of all the bodies multiplied by the perpendicular distance of their common centre of gravity from the same plane; and also of its corollary, that if any of the bodies lie on the other side of the plane, their distances must be reckoned as being negative. In applying this theorem to find the centre of gravity of any curvilinear space, by the application of either of the before-mentioned rules of approximation, each ordinate must be multiplied by its perpendicular distance from some given line, usually in a section near one of the extremities of the vessel: these products are then used as ordinates, and the rule is applied, and the calculations made, in the same manner as for finding the area of a space, the result, however, being the moment of the space. The moment of the space on the opposite or negative side of the line that was assumed from which to measure the perpendicular distances of the ordinates, is calculated by the application of the same means if the area be large; if small, a more simple method will easily suggest itself, and the moment thus obtained is subtracted from the former moment; the remainder is the total moment of the space, estimated from the assumed line, and this, divided by the total area of the same space, will give the distance of its centre of gravity from the assumed line. In this manner the centres of gravity of the load water-section and of the midship section may be found.

Application to curvilinear spaces by Atwood's rules;

to solids.

The position of the centre of gravity of the displacement is found by the application of the same rule of approximation. In order to determine its vertical distance below the load water-section, a series of equidistant horizontal sections must be drawn; then the area of each successive horizontal section is multiplied by its perpendicular distance below the load water-section, and these products are used as ordinates in either of the rules. The result is the moment of the space between the load water-section and the lowest horizontal section; to this must be added the moment of that part of the body which is below the lowest horizontal section. This will be obtained by multiplying its solid content into the vertical depth of its centre of gravity below the load water-section; the sum of these two moments is the moment of the whole displacement, estimated from the load water-section; and this moment, divided by the total displacement, will give the vertical distance of its centre of gravity below that load water-section. The position longitudinally of the centre of gravity of the displacement is obtained in a similar manner, by calculating the moment of that part of the displacement which is situated before some one of the transverse vertical sections, and also the moment of that part of the displacement situated on the opposite or negative side of the same section; then subtracting the negative moment from the positive, the remainder, which is the moment of the whole displacement estimated from the assumed vertical section, divided by the total displacement, will give the distance of its centre of gravity from the assumed vertical section.

Means of shortening foregoing calculations.

Instead of multiplying each ordinate by its perpendicular distance from the given line or plane, it is more convenient to multiply the successive ordinates by 1, 2, 3, 4, &c., and the sum of these products by the common distance between the ordinates, which of course produces the same result. A little consideration, in the course of performing the foregoing calculations, will suggest methods by which some of the labour may be lightened; such as the arrangement of the results in tabular forms, and the connecting the calculations for determining the areas, contents, or moments of those portions of the curves or solids towards the extremities with the general calculations. The foregoing account of the method of making the above calculations is given merely as an outline. For some of the more minute details, see Inman's Notes to Chapman; and mature consideration of the principles on which the calculations are founded will suggest all that can be further required.

Recapitulation.

The constructor having completed the foregoing calculations, will have ascertained the area of the midship section, the area of the load water-section, the displacement, the positions of the centres of gravity of these two sections, and also the position of the centre of gravity of the displacement. The areas of the two sections, and the positions of their respective centres of gravity, were required to be determined, on account of the influence of these areas and these positions on the content of the displacement, and the position of its centre of gravity, and also in consequence of their influence on the stability of the ship. It must therefore be remembered, that if the results of these previous calculations do not accord with the intentions of the constructor, or are inadequate to the development of his design, he must make such alterations in his curves or in his dimensions as he may consider necessary, before proceeding further with his design. And if he shall have sufficiently informed himself on the theory of ships, he will be enabled to do so with considerable confidence at this stage of his progress, as to the final result of his work.

Conditions of equilibrium of a body floating on a fluid at rest.

We have before said that a body floating on a fluid is supported by the upward pressure of that fluid. This body will be in equilibrio when the direction of this upward pressure passes through the centre of gravity of the part of the body which is immersed in the fluid, and also through the centre of gravity of the body. These two centres will therefore be in the same vertical line, and this vertical line will be the line of intersection of the transverse vertical section in which the centres of gravity of the displacement and of the body are situated, with the longitudinal vertical section of the body. Consequently, when a ship is floating on the water in a state of rest, and only acted upon by the upward pressure of the water, the centres of gravity of the ship and of the displacement are in the vertical middle line of the same transverse vertical section.

when acted upon by an inclining force.

But when the ship is inclined by the action of some second force, as that of the wind, a part of the body which was previously immersed is emerged, and a part which was above the surface of the water is immersed; consequently the form of the portion of the body under the water is altered, and the centre of gravity of the displacement is carried over towards that side on which the increased immersion has taken place, while the position of the centre of gravity of the ship, with reference to its position in the ship, has remained unaltered, that being the point about which the revolution has taken place. But though the form of that part of the ship's body which is beneath the surface of the water after the inclination, will differ from the form of that which was beneath the surface before the inclination, the total displacement will continue the same, since the weight of the ship has not been either increased or diminished by the inclination; consequently the solid content, or the displacement of that portion of the body which is immersed by the inclination, will be exactly equal to the solid content, or the displacement of that portion which is emerged by the same cause.

Solids of emersion and immersion.

But the forms of these two solids, which we shall call the solids of immersion and emersion, are not necessarily similar, and therefore their centres of gravity are not necessarily situated in the same transverse vertical section of the vessel. If the centres of gravity of these two solids should be situated in the same transverse vertical section, the inclination of the ship will be round her longitudinal axis; but if the centre of gravity of the solid of immersion be situated either before or abaft the transverse vertical section in which the centre of gravity of the solid of emersion is situated, in either case the motion of the ship in performing the inclination cannot be round an axis coincident with its longitudinal axis; and the position of the centre of gravity of the displacement, in passing to leeward of the position which it occupied before the inclination took place, will be influenced by the relative situations of the centres of gravity of these solids of immersion and emersion.

Their effect on the centre of gravity of displacement.

As this irregularity of motion is injurious to the ship, it is desirable to obviate it by regulating the form of the body, both above and below the load water-section, in such a manner that the centres of gravity of the solids of immersion and emersion may be in the same transverse vertical section of the ship. The form of that part of the body situated above and below the load water-line is also dependent upon the following considerations. Although the total displacement after the inclination must necessarily be the same as that before the inclination, the shape of the ship's body may be such that there will be a tendency to immerse a greater or a less solid on the one side than is emerged on the other; which tendency will have the effect of causing the axis of rotation, and consequently the centre of gravity of the ship, to rise or fall in space during the inclination, and fall or rise in space during the return to the upright position; for since the total displacement of the ship continues constant, the solid which is actually immersed cannot exceed that which has emerged.

Their effect on the centre of gravity of the ship.

It is therefore evident that the existence and extent of this motion must depend upon the position of the centre of gravity of the ship, and also on the form of those parts subject to alternate immersion and emersion. For the better illustration of this point, we will suppose a ship of such a form, that when she is floating upright on the water, her sides between wind and water, that is, those parts of her sides subject to the alternate immersion and emersion, are vertical.

First case.

We will first assume that the centre of gravity of this ship is coincident with the centre of gravity of the load water-section. In this case there will evidently be no tendency in the ship either to rise or fall during the inclination, because the two prismatic solids intercepted between the load water-sections before and after the inclination are equal, and the axis of revolution of the ship is coincident with the line of intersection of the two load water-sections.

Second case.

Now, if we assume the centre of gravity of the ship to be situated beneath the load water-section, and the inclination to take place, this centre being the axis of inclination, there would be a much larger solid immersed than was emerged, because the line of intersection of the two load water-sections would be to windward of the longitudinal vertical section of the ship; but in order to restore the equilibrium between the upward pressure of the water and the weight of the ship, the axis of rotation or centre of gravity of the ship must rise until these two solids become equal.

Third case.

Again, in the case when the centre of gravity of the ship is situated above the load water-section, it will be evident that the tendency of the inclination of the ship round it would be to raise a larger solid out of the water than would be immersed on the other side, unless the weight of the ship, in its effort to restore the equilibrium between the upward pressure of the water and itself, were to cause the centre of gravity of the ship to be lowered until the two solids became equal.

General conclusions.

Now, if we suppose the sides of this same ship were formed in such a manner as to fall outwards from the load water-section upwards, we shall easily perceive, that in the case where the centre of gravity was supposed to be beneath the load water-section, the injurious quality would be increased; while in the case in which it was supposed that the centre of gravity was above the load water-section, it would be diminished. The foregoing examples are sufficient to illustrate the principle on which this cause of uneasiness of motion in a ship depends, and also to point out the means which must be taken to obviate it. We see, then, that it is essential, not only that the centres of gravity of the solids of immersion and emersion should be in the same transverse vertical section, but also that these solids should be as nearly equal to each other at all inclinations as possible, and that the greater the deviation from equality between the solids of immersion and emersion, the greater the strain the ship will be subjected to, and the greater will be the uneasiness of her motions.

Adjustment of these solids.

In order to obviate this fault, it would be necessary to compute the exact position of the centre of gravity of the ship when completely ready for sea, that the correct prismatic solids of immersion and emersion might be ascertained and adjusted to equality, and to have their centres of gravity in the same transverse vertical section.

Labour attendant on determining centre of gravity of ship.

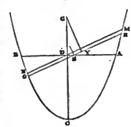
But the computation of the exact position of the centre of gravity of a ship completely fitted is a task of such magnitude, and, in consequence, of such hazard of incorrectness, that it can scarcely be considered practicable. Its position must be determined in relation to the three dimensions, length, breadth, and depth; relatively to two of these, however, it is ascertained from the consideration that it is necessarily in the same transverse vertical section as the centre of gravity of the displacement, and that, as it must also evidently be in the longitudinal vertical section of the ship, it must be in the line of intersection of this transverse vertical section with the longitudinal vertical section of the ship. But its position in relation to the load water-section, if not determined by experiment, must be ascertained by a most tedious and laborious calculation of the moments of the weights estimated from the load water-section, the sum-total of which moments being divided by the displacement of the ship, will give the perpendicular distance of the centre of gravity from the load water-section. This process has been gone through for several two-decked line-of-battle ships at the late School of Naval Architecture, and it was ascertained that the positions of their centres of gravity varied from seven to nine inches above the load water-section. We shall, in its proper place in this article, describe the manner of finding experimentally the position of the centre of gravity of a ship, merely here premising, it is assumed generally, that in ships of war the centre of gravity is rather above the load water-section.

In almost all classes of vessels, several of the transverse vertical sections on each side of the midship section are similar and equal to it, and generally the form of these sections is such, that there would be but little disturbance, during the inclination of the ship, in the adjustments of the solids of immersion and emersion; but the sections before and abaft these, as they approach the extremities, become more dissimilar in those portions of them above and below the load water-section; consequently, although, as has before been said, the total volumes of immersion and emersion must necessarily be equal, the areas of the sections of the immersed and emerged solids, at any given transverse vertical section of the body, need not be equal; it becomes therefore necessary to determine the position of the intersection of the inclined load water-section with the load water-section of the ship in her upright position.

To determine line of intersection of horizontal with inclined load water-section.

Suppose G (fig. 1) to be the centre of gravity of the ship, AB the water-line when she is upright, and let it cut the vertical line GC in the point D. From the centre of gravity G draw GY, making the angle DGY equal to the supposed angle of inclination of the ship. Take GY equal to GD, and through the point Y draw the line OR perpendicular to GY. Then OR is the water-line which the ship will assume after the inclination. Let this inclined water-line intersect the water-line AB in the point S. Through D draw NM parallel to OR. It is clear that, supposing the centres of gravity of the solids of immersion and emersion to be in the same transverse section, in every vertical transverse section of the ship the distance DS will be the same, and the several points S, S, S, will be in the straight line forming the intersection of the two load water-sections, which line of intersection will be parallel to the longitudinal axis. Now, if, by a calculation of the contents of the solids of immersion and emersion, which are represented in the figure by the triangles ASR and BSO, which contents may be calculated by either of the rules for approximation, they are not found to be equal, they must be altered until they become so. In order to find the position of the point S, or the distance DS, we have the area ASR equal to the area BSO, which call equal to A, and let the area DSRM $= a$, and the area DSON $= b$,

Fig. I.



$$\begin{aligned} \text{then ADM} &= \text{A} + a, \\ \text{BDN} &= \text{A} - b, \\ \text{and ADM} - \text{BDN} &= a + b = \text{MNOR} \\ &= \text{MN} \times \text{ST nearly}, \\ &= \text{MN} \times \text{DS} \times \text{sin. of inclin.} \end{aligned}$$

$$\text{or DS} = \frac{\text{ADM} - \text{BDN}}{\text{MN} \times \text{sin. of inclin.}}.$$

In order to obtain the areas of the sections of the prismatic solids, chords may be drawn in each, which will divide it into two others, a triangular and a parabolic area. The triangular area will be equal to half the product of the base multiplied into its perpendicular height. The parabolic area will be equal to two thirds the base multiplied into its perpendicular height. The moment of each of these areas may then be found by taking the sum of the product of the area of the triangle multiplied into the distance of its centre of gravity, estimated along the inclined line from the point S; and that of the product of the parabolic area multiplied into the distance of its centre of gravity, also estimated along the inclined line from the point S.

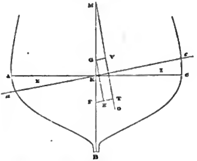
Explanation of the term stability.

We have said, that when a ship is floating in equilibrium on a fluid, the vertical upward pressure of the fluid acts in the straight line passing through the centres of gravity both of the displacement and of the vessel; but that when she is inclined by the action of any force, as that of the wind, the centre of gravity of the displacement is carried to leeward of its former position; and as the vertical pressure upwards of the fluid still takes place at the centre of gravity of the displacement, its direction should also pass to leeward of the position of the centre of gravity; and thus a force is generated the tendency of which is to enable the ship to recover her upright position. We will now investigate the expression for the value of this force, in order to show the principle on which the actual calculation of its amount in ships is necessarily founded.

### *Investigation of a General Expression for the Stability of a Ship, and Description of the Method of calculating the Stability.*

Let ABC (fig. 2) be the midship section of a ship, and AC the line of its intersection with the surface of the water. Suppose *ac* to be the same line when the ship is inclined, K being the point of intersection of the two lines. Now, by the inclination of the ship, of which we have taken the midship section to be a representative, a solid will be immersed on the lee side of the longitudinal axis, and an equal solid emerged on the weather side of the same axis. Call these solids respectively I and E, and suppose them to be concentrated in their respective centres of gravity. Let the horizontal distance between the centres of gravity of these two solids be *b*. Then, since the inclination of the ship has had the effect of taking the solid E from the displacement on the weather side of the middle line, and has added the solid I to the displacement on the lee side of the middle line, the same effect is produced as if the solid E had been transferred to I; and the moment produced by this transfer, which would be *b*I or *b*E, is the moment which is actually produced in the horizontal direction along the distance *b*.

Fig. 2.



Let G be the centre of gravity of the ship, F the centre of gravity of the displacement when the ship is upright, O the centre of gravity of the displacement when the ship is inclined. Draw OM perpendicular to *ac*. Then, after the inclination, the line OM will be vertical. From F and G draw FT and GV, perpendicular to OM, and from G draw GZ parallel to MO, cutting FT in Z.

Now, when the ship has inclined so that the point O becomes the centre of gravity of the displacement, the upward pressure of the water acts on the then vertical line OM, with a force equal to the weight of the ship, because it supports that weight; that is to say, with a force equal to the displacement, which we will represent by D. But the axis of revolution is the point G the centre of gravity, and GV being drawn from this point perpendicular to the direction OM in which the force acts, D the displacement multiplied by GV, its perpendicular distance from the axis of rotation, will be the force exerted to right the ship, or make it resume its upright position. But, by the construction,

$$D \times GV = D \times FT - D \times FZ.$$

Now $D \times FT$ is the horizontal moment of the displacement produced by the transfer of the solid from the weather to the lee side of the middle line; it is therefore equal to the horizontal moment $bI$, and consequently we have the effort to right the ship, or the moment of stability, as it is called, $= bI - D \times FZ$.

But if $s$ be taken = sin. of inclination,

$$FZ = s \times \text{rad. } FG,$$

or if $FG = d$, then

General expression. Its value.

moment of stability $= bI - D \cdot d \cdot s$.

Hence, in order to calculate the actual moment of stability of a vessel at a given angle of inclination,

1. Assume an inclined load water-section, cutting the horizontal load water-section at an angle of which $s$ is the sine; and suppose the assumed inclined and the horizontal load water-sections to intersect each other in their common intersection with the longitudinal vertical section of the ship.

2. Find, by the methods of approximation, the solid contents of the two prismatic solids of immersion and emersion, intercepted between the segments of the inclined and the horizontal load water-sections.

3. Find, by the method of approximating to the area of plane surfaces, the area of the above-mentioned assumed inclined section.

4. Find the value of DS (fig. 1), which has been shown to be equal to the difference between the contents of the prismatic solids of immersion and emersion, already found, divided by the product of the area of the assumed inclined section, into $s$, the sine of the angle of inclination.

5. Through the point S draw a section parallel to the assumed inclined section; find in each vertical transverse section the areas of each of the sections of the true prismatic solids of immersion and emersion; and also find the horizontal moments of these areas from the point S.

6. Find the horizontal distance of the centre of gravity of the whole emerged solid from S, assuming the emerged solid to be equal to half the sum of the two solids of immersion and emersion, which are intercepted between the segments of the assumed inclined load water-section and the horizontal load water-section.

7. Find also the horizontal distance of the centre of gravity of the whole immersed solid from S, assuming the immersed solid to be equal to half the sum of the same two solids of immersion and emersion.

8. Add these two distances together; their sum will be the horizontal distance between the centres of gravity of the solids of immersion and emersion. Take the product of this distance multiplied into half the sum of the solids of immersion and emersion, and we shall have the value of the positive part of the expression for the moment of stability, or the value of $bI$.

9. The product of three quantities, the displacement, the distance between the centres of gravity of the ship and of the displacement, and the sine of the angle of inclination, will give the value of the negative part of the expression.

10. Subtract the value of the negative part of the expression from that of the positive part, and the remainder will be the value of the expression for the moment of stability of the ship at the given angle of inclination.

It will be seen that the calculation of the moment of stability of a ship is very laborious. Several of the steps above enumerated in order, will, however, have been already taken for other purposes. The calculations may be considerably shortened by assuming a value for the distance DS, or the distance that the point S is from the middle line of the ship. We have already described the method of ascertaining this distance correctly, but generally it may be assumed to be about two or three tenths of a foot at first; and if the solids of immersion and emersion are not found to be equal, or very nearly so, with that assumption, another point must be taken, either within or without the former, according as the solid of immersion or emersion is the lesser. If $e$ be the difference between the two solids, and $a$ the area of the first assumed inclined section, if $x$ be the perpendicular distance between the true inclined section and the section we have assumed, $ax$ will equal $e$ nearly, or $x = \frac{e}{a}$, which distance must be set off perpendicularly to the assumed section, and we obtain the correct position of the point S.

In order to determine the distance $d$ between the centre of gravity of the ship and the centre of gravity of the displacement, the distance of the centre of gravity of the ship above or below the load water-line must be ascertained. To avoid the labour attendant on obtaining the position of this point by calculation, it may be determined experimentally in each class of ships of war when fully stowed and equipped.

### *Method of ascertaining the Centre of Gravity of a Ship by Experiment.*

On what principles founded.

We shall describe two methods of performing this experiment. The first of these was proposed by Chapman, and he strongly recommended that it should be made on ships of all classes. The principle on which it is founded is as follows. Various weights on board are removed in a transverse direction, so as to cause the ship to incline; and the momentum of the total weight so removed will necessarily be equal to the moment of stability. Now the momentum of the weight removed will be equal to the product of the weights, the distance they are removed in a transverse direction, and the cosine of the angle of inclination; which quantity, therefore, is equal to the moment of stability. If W represent the weights, $a$ the distance they are removed, and $c$ the cosine of the angle of inclination; then, $bI - Dds$ being the expression for the moment of stability, we have this equation,

$$W \cdot a \cdot c = bI - Dds,$$

$$\therefore d = \frac{bI - W \cdot a \cdot c}{Ds};$$

in which $d$, the distance between the centre of gravity of the ship and the centre of gravity of the displacement, is the only unknown quantity, and may therefore easily be found.

Its application to the Scylla.

We shall now describe the method by which this experiment was applied to determine the centre of gravity of her majesty's ship sloop Scylla, of eighteen guns, and which was originally an eighteen-gun brig. She was lying in Portsmouth harbour in May 1830, under the command of Captain Hindmarsh, at whose request the experiment was performed, by the late Mr Morgan of the School of Naval Architecture, then a foreman of her majesty's dock-yard at Portsmouth, assisted by the writer of the present article.

Theory.

These particulars are mentioned because it was the first, if it be not the only, example, in this country, of determining the position of the centre of gravity of a ship experimentally.

The draught of water was taken very correctly, the water being smooth, and was found to be, forward eleven feet six inches, abaft fourteen feet ten inches and a half. The depth of the keel and false keels below the lower edge of the rabbet of the keel was, forward one foot nine inches, abaft one foot three inches. The ship was perfectly upright, all the weights, inclusive of the crew, being equally balanced on each side. A large quadrant marked to a scale of degrees, with a plumb attached to the centre, was fixed in the main hatchway, to measure the inclination. The stations of the carronades and long gun on one side were marked on the deck, they were then moved to the other side, keeping them in the same transverse lines; the shot, the hammocks, and the crew, were also passed over to the inclined side, under the same condition. The distance which every weight had been moved was then measured. The weight of the shot moved was known, the weights of the long gun and the carronades were taken from the weights marked on them, and the weights of the men and hammocks were obtained by weighing them. The inclination of the ship was then observed to be 6° 20′. The product of the weights which had been moved, multiplied into the distances they had been moved in a transverse direction, in feet, was equal to 264·5 tons. This moment, multiplied into the cosine of the angle of inclination, was evidently equal to the moment of the stability of the ship.

Let D be the displacement of the ship in tons; l the volume immersed by the inclination, also in tons; $b$ the distance between the volumes immersed and emerged; and $d$ the distance between the centres of gravity of the displacement and the ship.

$$\text{Then } bl - dD \times \sin. 6^\circ\ 20' = 264{\cdot}5 \times \cos. 6^\circ\ 20',$$

$$d = \frac{bl - 264{\cdot}5 \times \cos. 6^\circ\ 20'}{\sin. 6^\circ\ 20'\ D}.$$

By substituting the values of $bl$ and D obtained by calculation, in this expression, the value of $d$, the distance between the centre of gravity of the displacement and the centre of gravity of the ship, is obtained.

$$d = \frac{446{\cdot}2 - 262{\cdot}8}{50{\cdot}85} = 3{\cdot}6 \text{ feet}.$$

The distance of the centre of gravity of the displacement below the load water-line being equal to 3·97 feet, 3·97 — 3·6 = ·37 will be the distance of the centre of gravity of the ship below the load water-line at the time of making the experiment.

When the ship was at Spithead, completely fitted out, with every thing on board that was deficient at the time of making the experiment, and with her provisions and stores for four months, the draught of water was again taken, and found to be, forward twelve feet six inches, abaft fourteen feet ten inches. The weights of all the articles brought on board since the experiment amounted to 33·4 tons, and the moment of these weights calculated above the water-line at the time of sailing was = 193 tons; the height of the centre of gravity of the sails being estimated as in the case of a top-gallant breeze.

The moment of weights below this water-line at the time of making the experiment = 401 tons,

$$\frac{401 - 193}{494{\cdot}4} = {\cdot}42 \text{ feet}.$$

The situation of the centre of gravity of the ship was ·42 foot, or five inches, below the water-line, at the time of sailing.

Correctness of the experiment doubtful.

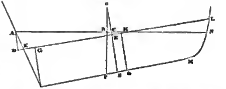
The correction to the result of this experiment which we see had to be made at Spithead, in consequence of the additional weight that had been taken on board after the ship had left the harbour, must, from the great hurry incidental to any observations made at the time of a ship's sailing, throw some doubt on the correctness of the final result; and it would be therefore desirable that it should receive the confirmation of a second trial on some similar ship, before its being assumed as conclusive to be the correct position of the centre of gravity of a sloop of war.

Experimental method when a ship is docked.

The second method was proposed by Mr Abethell, a member of the late School of Naval Architecture, and was published in the second volume of the Papers on Naval Architecture. It is applicable whenever a ship is taken into dock with the under side of her keel deviating from parallelism with the upper surface of the blocks. This is almost always the case; and it also not unfrequently occurs that ships are docked "all standing," and with so large a portion of their armament and stores on board, that the correction necessary to be made to the result which would be obtained by the experiment and investigation about to be described, in order to make that result agree with the circumstances of any additional armament and equipment, would be comparatively easy. We will now quote from the article in question.

"We will suppose, by the falling of the tide in the dock, the after-extremity of the keel to come first in contact with the blocks; then, as the tide continues to fall, the after-body is gradually forsaken by the water, and the fore-body further immersed, a constant equilibrium being maintained between the total weight of the ship and the pressure of the water against the immersed part of the body, until the ship is aground fore and aft. At any intermediate instant the ship may be considered as a lever of the second kind, of which the fulcrum is the transverse line or point of contact of the keel and after-block, and the power and weight the weight of the immersed volume and that of the ship respectively, each acting in the vertical line passing through its centre of gravity. As we can, by mensuration and calculation from the draught of the ship, easily find its weight, that of the immersed volume, and the perpendicular distance of the line of pressure from the fulcrum; in the equation of the moments, the distance of the vertical line passing through the centre of gravity of the ship is the only unknown quantity, which is therefore readily determined. AN (fig. 3) represents the water-line corresponding to the floating position of the ship, and KL the observed water-line just previously to the fore-part of the keel touching the blocks. The line PBO, perpendicular to AN, passes through the centre of gravity of the displaced volume AFMN, and consequently through that of the ship. Draw QH through the centre of gravity of the volume KFML, perpendicular to KL, and FG through the fulcrum F, parallel to QH. Then, putting the total displacement AFMN = V, KFML = $v$, and GH = $b$; if the line SEO, parallel to QH, be drawn at the distance GE from G equal to $\frac{bv}{V}$, it will, as well as PBO, pass through the centre of gravity of the ship, which will be in O, the point of their intersection.

Fig. 3.



"To obtain from these considerations a general expression for the perpendicular distance of the point O from the water-line AN, draw AD perpendicular to EG, and meeting it, when produced, in D; and, having calculated the values of AB and GE, put AB $= a$, DE or DG + GE $= d$, and the angle of inclination between the water-lines AN and KL $= \Delta$; then BO $= \left(\frac{d}{\cos. \Delta} \backsim a\right)\frac{1}{\tan. \Delta}$; which must be set off upon the perpendicular PBO, above or below AN, according as $\frac{d}{\cos. \Delta}$ is greater or less than $a$."

Other methods.

There are several other methods by which the centre of gravity of a ship may be found experimentally. One was proposed by Don Juan d'Ulloa, a Spanish writer on naval science, and a navigator and mathematician of very great eminence, whose works are among the best extant on the subject of the theory of ships. They have been translated into French; and the description and investigation of the experiment for finding the centre of gravity of a ship has been translated into English by Mr Read, in the Essays and Gleanings on Naval Architecture, a periodical work conducted for a short time with great ability by Messrs Laire, Read, and Chatfield, all members of the late School of Naval Architecture. Another method was proposed by a student at the same establishment, since dead, named Barton. This method was published in the fifth number of Papers on Naval Architecture.

Error in the assumption that the vertical pressure necessarily tends to diminish the inclination.

We have hitherto, throughout our investigations, assumed that the vertical pressure upward of the water to support a ship acting in the direction of its resultant, must exert a force tending to resist the force of the wind by which we have supposed the ship to be inclined. We shall now proceed to show that this is not necessarily the case, but that the tendency of this force may not be to act in the manner we have hitherto assumed it as acting; and that its effect is dependent upon the position of the centre of gravity of the ship, the point around which she is supposed to revolve in inclining. There are three cases which may occur. The first is, that the vessel, when acted upon by the force of the wind, may assume a permanent inclination. This permanent inclination would ensue if the resultant of the upward pressure of the water were, after the inclination, still to pass through the centre of gravity of the ship. The second case is that in which the vessel would recover the upright position immediately on the removal of the inclining force. This would ensue whenever the resultant of the upward pressure of the water, after the inclination, would pass on the immersed or lee side of the centre of gravity of the ship. The third case is that in which the effect of the vertical upward pressure of the water would be to increase the inclination of the ship. This would ensue whenever the direction of the resultant of the upward pressure would pass on the emerged or weather side of the centre of gravity of the ship. These three states of equilibrium, which arise from these considerations, are called the state of insensible equilibrium, of equilibrium of stability, and of equilibrium of instability.

Three cases.

### *On the Metacentre.*

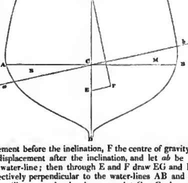
A limit to the position of centre of gravity of a ship.

It is evident, from the foregoing considerations, that there is some limit to the height of the centre of gravity of a ship, and below which it must necessarily be placed, in order that the upright position may be recovered; that is, that the ship, when inclined by the force of the wind, may be in an equilibrium of stability. The situation of this point was first investigated by Bouguer, who called it the *metacentre*, which name has been generally adopted by subsequent writers on naval architecture. Its height is determined in the following manner: The vessel is supposed to be inclined through an infinitely small angle of inclination, that the intersection of the new load water-section with that previous to the inclination may not be supposed to deviate from the middle line of either, so that the infinitely small solids of immersion and emersion may be considered to be equal to each other. Then the point in which the new line of direction of the vertical upward pressure of the water will cut the line of direction of the same vertical pressure before the inclination, is the point beneath which the centre of gravity must necessarily be situated to insure the vessel's floating on the water in the equilibrium of stability.

Height of metacentre

In order to determine the height of the metacentre above the centre of gravity of the displacement, let the half breadth at the water-line AB of the midship section ADB (fig. 4) $= y$. Let E be the centre of gravity of the displacement before the inclination, F the centre of gravity of the displacement after the inclination, and let $ab$ be the new water-line; then through E and F draw EG and FG respectively perpendicular to the water-lines AB and $ab$. They will meet each other in some point G. G, the point of their intersection, is the metacentre, and EG is the height of the metacentre above the centre of gravity of the displacement.

Fig. 4.



The triangles AC$a$, BC$b$ are equal, by the conditions of the construction; and if $x$ be the length of the prismatic solids of immersion and emersion, AC$a \cdot dx$ and BC$b \cdot dx$ are equal, and may be supposed to be concentrated in their respective centres of gravity M and N, MN being by construction $\frac{4}{3}y$. Then the moment of the transfer of the solid of emersion to the position of the solid of immersion $=$ BC$b \cdot dx \cdot \frac{4}{3}y$. Let A$a$ = B$b$ $= b$. But the triangle BC$b = \frac{yb}{2}$, therefore the moment of immersion $= \frac{2}{3}y^2 b dx$, therefore $\int \frac{2}{3} y^2 b dx = \text{D} \cdot \text{EF}$; but

$$b : y :: \text{EF} : \text{EG} \; .^{\cdot} \; b = \frac{\text{EF}}{\text{EG}} y.$$

By substituting and multiplying both sides by $\frac{\text{EG}}{\text{EF}}$

$$\int \frac{2}{3} y^3 dx = \text{D} \cdot \text{EG}, \qquad \int \frac{2}{3} \frac{y^3 dx}{\text{D}} = \text{EG}.$$

A measure of stability.

The height of the metacentre is the measure of stability used by the French naval architects, and indeed generally by all since the first investigation of its principles by Bouguer in his *Traité du Navire*. The error in its practical application is, that the investigation involves the erroneous supposition, that the transverse sections of the immersion and emersion are right-angled triangles, and that the horizontal distance between their centres of gravity is two thirds the breadth of the load water-line. These assumptions are only true at an infinitely small angle of inclination, and at such only, therefore, is the height of the metacentre a correct measure of stability. Atwood, who published two papers on the stability of floating bodies, in the Philosophical Transactions for the years 1796 and 1798, was the first who pointed out the error in the metacentric measure of stability, and who proved that it was necessary to involve the actual content immersed or emerged, and the correct distance between the centres of gravity of the solids of immersion and emersion, in the expression, in order to apply it to the measuring the stability of bodies at finite angles of inclination. It is therefore to him that the theory of ships is indebted for the correct solution of the problem on which the stability at finite angles of inclination depends.

st infinitely small angles of inclination.

Atwood's reasoning on the incorrectness of this measure.

Atwood agrees with Bouguer in his general reasoning on the metacentre, and even admits that it may be used at very small angles of inclination, as a sufficiently accurate measure of the stability; but asserts the danger of its application to practice as a measure at all angles. He shows that two ships may have precisely the same load water-section, which, supposing the relative distance between the centres of gravity of the ship and of the displacement equal in both ships, will determine the height of the metacentre to be the same, and consequently, according to the metacentric theory, the stability to be equal; and yet, from a difference in the forms of the ships' bodies within the limits of the immersion and emersion, the moments of stability, when correctly measured, may be very different. But while we state this as the result of Atwood's inquiry, we must observe, that the practical error between the metacentric method of Bouguer, and the certainly correct method investigated by Atwood, is not of any importance for small angles of inclination, especially in large ships; and further, that a constructor who is acquainted with Atwood's investigations, and who is therefore aware of the correct principles on which the stability of ships depends, may safely apply the metacentric method in his practice, as his bodies will be formed in accordance with the results of Atwood's investigations. It will only be in cases of some important alteration from previously existing form, dimensions, or services, that the labour attendant on the calculations involved in Atwood's expression will be necessary.

Practical error generally unimportant.

General conclusions.

The question may probably be stated to resolve itself nearly into this. That ships might be built, in which the stabilities calculated by the two methods would vary very considerably; also, that at very great angles of inclination the stabilities of ships, such in form as are sometimes built, would be found to differ very greatly when calculated by the two methods, but that a constructor acquainted with both methods would never construct a ship, using only the metacentric method in the progress of his work, which would be proved unstable if Atwood's calculations were applied to the finished design.

In applying the expression $\int \frac{\frac{2}{3} y^3 dx}{D}$ to find the height of the metacentre, we may again have recourse to the rules of approximation. The common rule for obtaining the area of a plane surface may be applied, substituting the cubes of the ordinates of the load water-section instead of the ordinates themselves.

The result will be the value of $y^3dx$, and two thirds of this value divided by the displacement will give the height of the metacentre above the centre of gravity of the displacement.

The reader who wishes to refer to cases of stability as connected with particular forms, should consult Atwood's papers in the Philosophical Transactions, or rather Mr Read's able simplification of them in the Essays and Gleanings on Naval Architecture, and also his Disquisition on the Metacentre, in Papers on Naval Architecture.

### *On the Principal Dimensions of a Ship.*

Dimensions dependent on displacement.

In a ship of war the efficiency of the armament is necessarily the primary object of the design; this must therefore determine the dimensions: also, whether in a fleet or in a single ship, the greatest effective force must be obtained at the least expense; or, as when ships are built, masted, rigged, and their armament completed, all of similar materials, their expenses will vary as their displacements, the object to be attained is the greatest effective force with the least displacement.

Variable quantities to complete load-displacement.

But there is another point involved in the question of the efficiency of the armament, which very materially influences the displacement. It is the time for which a ship is intended to maintain her armament in an efficient state, without other aid than that which she can carry. This brings us to the consideration of the variable quantities which are to be added to those before enumerated, to complete the load-displacement. The crew is dependent on the armament alone, and therefore is included in the term armament. But the provisions for this crew, and the stores for the wear and tear of the ship and the service of the guns, are dependent on the time that the ship is intended to remain at sea without replenishing these resources. It is evident, that the longer this time, the greater must be the displacement, and, consequently, the larger should be the dimensions in proportion to the armament.

Practical advantages attending wide-spread possessions.

It results, from the foregoing reasoning, that the nation with the most wide-spread possessions, and therefore the most frequent opportunities for refitting and replenishing her fleets, has the advantage over all others. For she may maintain equal armaments at less expense, or superior armaments at an equal expense; while she may also avail herself, in the one case, of additional velocity, which may be attained with the diminished displacement.

Many arguments might be deduced from the same considerations in favour of the principle of occasionally designing specific ships for specific services. These of course would only apply to the fleets of those nations which aspire to wide-spreading and predominant naval power.

Length and breadth, under what limitation.

We shall now offer some general remarks on the two dimensions, the length and the breadth. It will be evident, from the foregoing observations, that the minimum length is the space required for the perfectly efficient working of the guns, and that the minimum breadth is the space required for their recoil and effective service, without hindrance to the manœuvres of the vessel, in the most disadvantageous state of weather during which they can be used. This consideration necessarily involves a defined and a sufficient moment of stability. These minima are the dimensions due to the ship when masted and rigged, and with her armament completed: any increase is dependent on the displacement necessary for the additional stowage that may be required for a specific time of service, longer than that time for which the ship, as thus determined, would be adequate. Then the increased dimensions due to this increased displacement being ascertained, under the same conditions of perfect efficiency in the vessel, any increase of one dimension must be followed by a diminution of the other; or the displacement, and consequently the expense, will be above the limit required for the armament.

Effect of increase;

We shall now proceed to show the effect on the qualities of the vessel, of the separate increase of either dimension; always premising, that in each case all things else are supposed to remain the same, excepting the dimension under consideration. First, then, the length. The displacement, the stability, and the resistance to leeway, vary directly as the length; therefore we increase all these qualities in proportion to the additional length. But we also increase the violence of pitching and 'scending; for the momenta of the weights in the fore and after bodies vary as the squares of

of length,

their distances from the axis of rotation, consequently we increase the strain on the combinations of the structure; and as the strength to resist this strain varies inversely as the length, we diminish the power to resist this increased strain. By an increase in the length we also increase the effect of the resistance of the water to the rotation of the vessel in the manœuvres of tacking, wearing, and other changes of her course.

of breadth.

By increasing the breadth, and by breadth we mean the whole breadth of that part of the body included in the limits of the immersions and emersions, we increase the stability, which varies as the cube of the breadth. Also, the angular momenta of the weights, estimated from the axis of rotation, vary as the squares of their distances from that axis, and the momentum of the stroke of a wave is increased in the same proportion; therefore the increase of stability is accompanied by increased violence in the motions, and consequent increased strain on the combinations and materials of the structure, and especially danger to the masts, by which the safety of the vessel may be compromised. The stability of a ship being the quality on which the efficiency of her armament is essentially dependent, and which also, by enabling her to carry a press of sail in circumstances of danger, as a lee shore, or an enemy of superior force, is essential to her safety; the only limit to its increase is involved in the consideration of easiness of motion. But if this consideration be neglected, and the breadth be such that the moment of stability in proportion to the moment of sail is so large, or of such sudden increase, that the masts are endangered or the combinations of the structure prematurely destroyed, the object for which a large moment of stability was desirable is frustrated. The breadth, therefore, is limited by easiness of motion.

By increase of breadth we increase the stowage, which varies as the breadth; but since the direct resistance to the progress of the vessel also varies as the breadth, in this case we do not gain increase of stowage without an increase of the direct resistance.

Small ships should have greater relative breadth than large ships.

Having thus pointed out in general terms the effects of an increase either of length or breadth, we shall quote from a very able article in the fifth number of Papers on Naval Architecture, written by Mr Bennet, a member of the abolished School of Naval Architecture, containing some more particular observations on the breadth of vessels in proportion to their armament and in relation to their stability. "The capacities of ships increase as the cubes of their dimensions, whereas the stability increases as the fourth power of their dimensions. The inference to be drawn from this is, that small ships should have greater relative breadth than large ships. This, however, must be understood with certain limitations: it may be a general, but not an universal truth. Were all ships homogeneous; thus, if a navy consisted entirely of corvettes, the corvette of eighteen guns ought to be relatively broader than the corvette of 120 guns: this is a rule without any exception. It may be farther observed from the previous remarks, that the corvette of eighteen guns should be relatively broader than the three-decked ship of 120 guns; but if a ship were built to carry 120 guns on four or even on five decks, her relative breadth should then approximate to, and should most likely exceed, that of the corvette, in order to insure sufficient stability. The consideration of this simple case may tend to elucidate the principles of stability when applied to cases of greater difficulty. If a three-decked ship of 120 guns is to carry the same force on a greater number of decks, her absolute length would of course be reduced; and supposing her breadth to remain the same, the positive part of the expression of stability would be thereby diminished. The displacement, which is one element of the negative part of the expression, would probably remain nearly the same, as the additional weight of topside might counterbalance the reduction of weight occasioned by less length. If the displacement be equal in each case, the draught of water would be increased from the diminution of length; this would lower the centre of gravity of displacement, which, together with the centre of gravity of the ship being raised by the additional weight above the water, would increase the distance between the centre of gravity of the ship and that of the displacement. On the whole, therefore, the positive part of the expression would be diminished and the negative part increased, so that the stability would be less in a ship of the same force and breadth as another ship, but which carried her guns on a greater number of decks.

Least vessel of each class liable to be deficient in stability.

"Having seen the necessity, in the case of a ship carrying the same number and weight of guns as another ship, but on more decks, of increasing the breadth, in order to avoid a deficiency of stability, we may evidently trace the same principle existing between the largest ship of an inferior class, and the least ship of a superior class, in which, if the number of guns be not equal, it approximates sufficiently to make the application apparent; so that in the several gradations of corvettes, frigates, two-decked ships, and three-decked ships, the least vessel of each class is liable to be wanting in stability, from its small comparative dimensions not sufficiently counteracting the effect of additional decks and guns. In this case, therefore, above all others, particular care should be taken to give sufficient breadth to compensate for a tendency to deficiency in stability; so that, without much liability to error, we may conclude,—

General conclusions.

"1st, That the small frigate should be relatively broader than the large corvette.

"2d, That the small two-decker should be relatively broader than the large frigate.

"3d, That the small three-decker should be relatively broader than the large two-decker.

"Between each of these varieties there will be a certain point, if the expression may be used, where the superior and inferior classes of ships should have the same ratio of length to breadth. This arises from the enlargement of their dimensions increasing the stability in a greater proportion than the weight of additional decks and guns diminishes the stability. Thus,

"4th, The middling-sized frigate should have the same ratio of length to breadth as the large corvette.

"5th, The middling-sized two-decker should have the same ratio of length to breadth as the large frigate.

"6th, The middling-sized three-decker should have the same ratio of length to breadth as the large two-decker.

"As corollaries from the first three observations, we may remark,

"7th, That the large corvette should be relatively broader than the large frigate.

"8th, That the large frigate should be relatively broader than the large two-decker.

"9th, That the large two-decker should be relatively broader than the large three-decker."

Draught of water dependent on locality.

The depth or draught of water is more dependent on local circumstances than on accurate principles. A fleet intended to traverse the Atlantic may have far different draughts of water from the ships of one that is destined for the Baltic. Cruizers for the open seas may be much deeper than those intended to watch an enemy's coast.

May be approximated to.

The average light draught of water which a ship will swim at, or the average load draught of water that will be found necessary for her, may be easily and accurately approximated to by means of the calculations of the displacement which have been already explained.

The actual water-line, with the difference of draught of water which it may be considered necessary to insure to the vessel, may also be approximated to in the design of a ship, or approximately determined from the drawing of a ship already designed, on the following principle. Suppose the body of the vessel to be divided, at the vertical transverse section passing through the centre of gravity of the displacement, into two, the fore and after bodies; then, if the depths of the centres of gravity of the displacements of the two parts of the vessel below the assumed water-line be determined, a line joining these centres of gravity will necessarily be nearly parallel to the seat which the vessel will assume in the water.

Tables have been formed by Mr Cradock, a member of the late School of Naval Architecture, for facilitating the stowage of the ballast in ships, in order that they may sail at a determinate trim. These tables, being deduced from various ships in her majesty's service, afford approximations for similar vessels; but when there is a dissimilarity in size and form, we quote from the preliminary remarks to the tables, "in order to place the ballast in such a position, that when all the weights are on board no alteration in it shall be necessary. The difference between the light draught of water, and that to which it may be proposed to bring the ship when fully equipped, being known, the centre of gravity of this part of the displacement may be found. And if through this point a transverse vertical plane be supposed to pass, the ballast must be so placed that its moment from it, together with the moments from the same plane of all the other weights put on board, may be equal to nothing." The length of these calculations is a convincing proof of the value of such approximating tables.

Difference of draught of water.

It is almost an universal custom in all vessels to give a greater draught of water abaft than forward. Occasional attempts have been made to discontinue this practice, as involving a supposed unnecessary increase in the water required for floating a ship; but the increased draught of water for the after-body has been reverted to as essentially requisite in practice.

Its advantages.

There are several minor advantages which result from this arrangement; such as the more easy and unchecked flow of the water to the rudder, and its consequent increased effect in governing the motions of the ship; also the diminution of the negative resistance which the vessel would otherwise experience from the greater difficulty with which the flow of water would fill the vacuity caused by the passage of the vessel, if the fulness of the after-body were such as would be required to preserve an even draught of water; and again, the adjustment of the resultant of the resistance of the water to that position of the masts which experience has determined to be requisite for the facility of manœuvring the sails. But the principal reason for the inequality in the draught of water appears to be the advantage which results from it to the more easy regulation of the motions of the vessel by an adjustment of the resultant of the resistance of the water on the lee side when on a wind.

This will be more apparent in a future portion of this article, in which we shall consider the forces which act on a ship when in motion. The idea intended to be conveyed is, that the flatness of the after-body along the deadwood may be considered as a reserve of lateral resistance, to be brought into operation whenever the pressure of the water on the lee-bow would otherwise draw the resultant of the water too far forward.

Dimensions of merchant-ships.

The dimensions of the merchant-shipping of England have been so shackled by the operation of the tonnage laws, that it is in vain to expect to find in their proportions any approximation even to those which experience has proved are most advantageous for safety and for velocity. We take the following table from Hedderwick's Treatise on Marine Architecture, which being the most modern work on the mercantile navy, we presume contains details of the most modern practice.

"Sloop Margaret, 60 tons, breadth to length as 34·8 to 100.
"Smack Regent, 142 tons, breadth to length as 34·2 to 100.
"Smack Matchless, 170 tons, breadth to length as 33·4 to 100.
"Smack Royal Sovereign, 204 tons, breadth to length as 32·0 to 100.
"Schooner Charlotte, 101 tons, breadth to length as 31·5 to 100.
"Schooner Glasgow, 155 tons, breadth to length as 31·0 to 100.
"Brig Down Castle, 149 tons, breadth to length as 30·0 to 100.
"Brig William Young, 303 tons, breadth to length as 28·6 to 100.
"Ship Mary, 368 tons, breadth to length as 27·9 to 100.
"Ship Albion, 505 tons, breadth to length as 25·10 to 100.

"The average depth of the sloops and smacks is about five ninths of their breadth; schooners and brigs, from seven twelfths to three fourths; and large brigs and ships, from three fourths to two thirds."

This immense proportionate depth is the natural result of the old rule for calculating the tonnage; according to which tonnage the worth of the ship was estimated, and all the dues and duties levied. The rule involved only the dimensions of length and breadth, and consequently left the depth to be increased without limit, or rather with no other limit than the depth of the harbours the vessel was destined to trade to. Now, Chapman, in the *Architectura Navalis Mercatoria*, gives an expression to which he says the velocity may be considered proportional: it is $\frac{B^{\frac{1}{2}} \cdot L^{\frac{4}{3}}}{D^{\frac{3}{2}}}$; in which B represents the breadth, L the length, and D the depth to the bilge; from which expression it is evident the depth is the dimension the most detrimental to the velocity. Valuable tables of some of the elements of design of the present classes of merchant-ships have been published by Mr Parsons, formerly of the School of Naval Architecture, under the title of Scales of Displacements.

## *Investigation of the Forces which act on a Ship when in Motion, as they influence her Form and Qualities.*

Preliminary observations.

We have now described the methods by which the several calculations for determining the elements of the design for a ship may be performed; and have also pointed out, in general terms, the dependence of the several principal dimensions upon each other, and their respective influence on the qualities of a vessel. We shall proceed to offer some more particular remarks on the forces of the wind on the sails and of the water on the hull when the ship is in motion, and investigate some of the principal phenomena of their action; as it is only by a consideration of the influence of these forces on the motions of the vessel that the naval architect can form a correct idea of the essential requisites for the design of a ship's body, or the position or proportion of the masts, the area of the sails, and the position of their centre of effort. The investigations into which we shall enter in this portion of the subject may perhaps be found in some cases equally useful to the sailor as to the naval architect, as he will trace in them the means for developing the powers of the vessel he may command, or of obviating by the appropriate remedy any error inherent to her design or equipment.

Questions interesting alike to the sailor and the naval architect.

Pitching and 'scending.

The motion of pitching is generally the most violent action to which a ship is subjected, and the most injurious, both to the connection between the parts of her structure, and the velocity of her sailing. It is the longitudinal motion, caused by the variable support afforded to the body by the waves as the vessel passes over them when on a wind, and by the constant action of the gravity of the unsupported part of the body to recover the state of equilibrium which, before the commencement of the motion, had existed between it and the buoyancy of the fluid. The motion will continue as long as the course of the vessel remains the same in relation to the set of the seas, and as long as the inequality of the surface of the water continues; but when the direction of the wind on the vessel becomes such that she no longer meets and passes over the seas, so that it may be said to act in conjunction with gravity, in offering a constant opposition to the vessel's oscillations, the motion will cease. For these causes, the pitching motion can only exist to any great extent when a vessel is on a wind: then, its force will depend on the degree of inequality of the surface of the water, on the quickness or slowness of the succession of the waves, on the direction in which they strike the bow of the vessel, and on the shape of the bow, as this greatly influences the degree of violence with which it meets the water, and the resistance it opposes to submersion.

may be diminished.

The least injurious action of pitching occurs when the state of the sea is such that the motion of the ship may be supposed to take place round a line passing through its centre of gravity as a fixed axis of rotation; for then the motion may be compared to the oscillations of a pendulum, and its extent may, in a great degree, be regulated by either increasing or diminishing the length of the isochronal pendulum, according as the state of the sea appears to require the oscillations to be made in longer or shorter periods. These effects may be severally produced, by removing weights further from, or by approaching them nearer to, the axis of rotation; that is, by increasing or diminishing the moments of inertia of the fore and after parts of the body round its axis of rotation.

But it is, as has before been said, only in some states of the sea that the pitching motion in a vessel can be compared to the oscillations of a body round a fixed axis of rotation passing through its centre of gravity, and where the moments of inertia of both the fore and after bodies oppose the motion; for, under many of the circumstances of heavy seas, though, at the commencement of the motion, the axis of rotation may pass through the centre of gravity of the ship, it will pass abaft it as the wave passes aft. In this case, then, the moment of inertia of the body before the axis of rotation, which, when this axis passed through the centre of gravity, was equal to the sum of the particles in that body multiplied by the squares of their distances from the axis of rotation, will become, at any instant afterwards, when the axis of rotation shall have passed abaft the centre of gravity, increased, by the difference between this quantity and the sum of the products of the particles in the then fore-body, multiplied by the squares of their distances from the new axis of rotation; consequently the moment of inertia of the fore-body will be constantly increasing until the end of the motion, while the moment of inertia of the part abaft the axis of rotation will be constantly diminishing, under the same limits; that is, the force which has an injurious effect on the violence of the pitching increases, while that which diminishes its violence decreases. As the direction of the motion of the waves is opposed to that of the vessel, the momentum with which the bow of the ship will meet the sea at the expiration of the motion, is equal to the sum of the momenta of the bow and the sea; and this impulse is often so great in practice, as to be sufficient completely to check, for several seconds, the motion of the vessel in her course. Frequent recurrences of these shocks must, therefore, not only be extremely injurious to the strength of the fabric of the ship, but must materially affect her progress through the water, and may even, in some situations, involve her safety, from the increased liability of shipping seas, especially in deep-waisted vessels; and also, unless a ship can contend with advantage against a head sea, her chance of escaping the danger of a lee shore must be considerably diminished, as in such a situation her safety would in a great measure depend on the possession of that property.[1]

Evils resulting from its violence.

Angular momentum.

From these considerations, it is evident that every alteration which can be made to diminish the extreme violence of this motion, when it takes place under the circumstances which have been described, either by lessening the moment of inertia of the fore-part of the ship, or by giving that part the form which will the most conduce to render its impact with the water more gradual, must be advantageous with respect to the velocity, to the preservation of the strength of the ship, and even to the increasing the safety of the crew. But since the bow of a ship is subjected to shocks of such a violent nature, it must necessarily consist of a vast combination of materials to insure an adequate degree of strength to resist them: great care, however, should be taken that there be not more weight than this renders absolutely necessary. These considerations point out at once one limit to the position of the masts; for it is evidently desirable that the weight of the fore-mast and the pressure of the head-sails should act with as little injurious effect in increasing the violence of the pitching, as is consistent with the necessity for head-sail; this will be better understood as we proceed with our investigation of the various forces which act on a ship when in motion.

A limit to the positions of the masts.

Resultants of forces.

When the ship is under sail, there are two forces acting on it; the one, the force of the wind on the sails, to propel the ship; and the other, the resistance the water opposes to her motion. These forces, immediately the ship has acquired the velocity due to the strength of the wind, are equal, and, as is the case with all forces, may each be reasoned on as if acting on only one point of the surface over which its effect is diffused. This point is that in which, if the whole force were to be concentrated, its effect would be the same as when dispersed over the whole area: it is usual to call these, "resultants of forces," and the points on which they are supposed to act, "centres of effort."

Centres of effort.

Action of wind on the sails, and water on the hull.

From what has been before said, the resultant of the force of the wind on the sails, and the resultant of the force of the water on the hull, are equal; the one acting on the weather side of the ship, in the direction into which the force of the wind resolves itself, and the other opposed to it, acting on the lee side, in the direction into which the force of the water resolves itself; and their effect is necessarily in proportion to their distance from the centre of gravity. If they are equally distant, they will destroy each other, and the ship will remain at rest with respect to the line of its course; if the resultant of the resistance of the water passes before the resultant of the wind, the ship will turn to the wind; but if the resultant of the wind passes before that of the water, the effect will be the contrary, and the ship will fall off from the wind. In either case it will be necessary to equalize the forces, by the action of the water on the rudder, on its lee side, to bring the resultant of the water more aft, and on its weather side to destroy a part of the effect of the wind. This is the principle of the action of the wind on the sails, and of that of the water on the hull, with respect to the course of the ship through the water; and it is on these considerations only that the various alterations can be regulated, which it may from time to time be necessary to make in the trim either of the sails or of the ship; and hence the accurate determination of the positions and directions of these two forces is a point of great importance in naval architecture. The position of the centre of effort of the wind on the sails may be found under certain reservations; and that being known, enough is determined to lead to correct conclusions on the other circumstances attendant on the subject.

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[1] Mr Henwood, a member of the late School of Naval Architecture, has advanced some new views on the subject of the pitching and 'scending motions in ships, which we think of sufficient importance to endeavour to explain. They are as follow,—that these longitudinal motions of a ship depend both on the form of the immersed part of the body, and on the positions of the various weights which compose the lading or equipment; and the form of a ship, and the positions of the weights, determine the situation of the centre of gravity through which the axis of the pitching and 'scending motions passes. It is the position of this point or axis which, Mr Henwood has stated and endeavoured to show, might and ought to be so determined in all ships, that the pitching and 'scending motions would be diminished to the lowest possible degree.

In order to construct a ship on this principle, the fore-part of the ship, viz. that before the centre of gravity, would be formed in the usual manner; but the after-part would be constructed so as to have precisely the same cubic content as the fore-body, and its centre of gravity at the same distance from the centre of gravity of the ship as that of the fore-body.

In the stowage of a ship thus constructed, the weights must be so disposed that one half of the total weight of the ship and her equipment may be on each side of the vertical and transverse plane, through the centre of gravity.

The object intended to be gained by the fulfilment of the above conditions is, that a ship should perform her longitudinal or pitching motions exactly as she does her lateral or rolling motions; and that as there is the same tendency to roll either side equally deep, so there should be a like tendency of the fore and after ends to pitch and 'scend. The pitching and 'scending motions would, Mr Henwood considers, thus be reduced to a minimum, and the velocity of sailing retarded in the least possible degree.

This proposed desideratum in the construction of ships is irrespective of the form of the midship section, or of the water-lines, &c. It is simply the constructing of one end of a ship upon the basis of the other end, so as to insure the attainment of the object in view,—the least possible degree of pitching and 'scending.

Centre of effort of wind before centre of gravity of ship,

In order to find the distance of the centre of effort of the wind on the sails before the centre of gravity of the ship, the moment of each sail is calculated by multiplying its area by the horizontal distance of its centre of gravity from that of the ship; the sum of the negative moments, or those abaft the centre of gravity of the ship, is then subtracted from the sum of the positive moments, or those before the centre of gravity of the ship; the remainder is then divided by the total area of the sails, and the result gives the required distance of the centre of effort of the wind on the sails before the centre of gravity of the ship. The situation of this point with respect to the length of the vessel must determine in a considerable degree the positions of the masts; for experience has proved, that it is among the most essentially requisite good qualities of a ship, that she shall carry a weather helm.

determines positions of masts.

Effect of rudder.

Reasoning of Don Juan.

It does not at first appear evident why the rudder should have more effect on the ship when it meets the water on one side of the middle line, than it has when put to an equal angle on the other side; the reason has, however, been partially explained by several writers on naval architecture, from the consideration of the direction of the motion of a ship through the water. Among these Don Juan has been the most explicit. The reasoning he pursues is as follows: That as a great portion of the force of the wind, in all oblique courses, tends to drive the ship bodily to leeward, and as this effect cannot by any means be wholly destroyed, the true course of the ship is not in the direction of its own middle line, but in that of a line passing from the lee bow to the weather quarter, parallel to the ship's wake; and he supposes that the fluid meets the rudder in the direction of this line of lee-way, both on the lee and weather side of the ship; and that therefore, when the helm is a-weather, the angle of incidence of the fluid on the rudder is equal to the sum of the angle of lee-way, and the angle made by the direction of the rudder with the middle line of the ship; while, when the helm is a-lee, the angle of incidence is only equal to the difference between these two angles, and that therefore, when they are equal to each other, this difference vanishes, and all action of the water on the rudder ceases; and this, under Don Juan's suppositions, would occur when the rudder was in the direction of the line of lee-way. And hence, as the most advantageous general position for the rudder is that in which, by offering no obstacle to the passage of the water, it offers no resistance to the velocity of the ship, and yet may by the least variation from this inactive position be brought to act effectively, it follows, either that Don Juan's reasoning is incorrect, or that the most advantageous general position for the helm should be a-lee. But experience proves, that with the helm a-lee, the rudder would not have the effect on the ship which has been described; therefore, although Don Juan's reasoning shows the main principle of the greater effect of the rudder when it is to leeward of the middle line of the ship, than when it is inclined at an equal angle to windward of the middle line of the ship, it is insufficient to account for the fact, that the general position of the helm should be a-weather; indeed his reasoning, on the contrary, proves that it should be a-lee; which error arises from the incorrectness of the assumption which he makes, that the fluid meets the rudder on the weather side of the ship, in the direction of the line of lee-way. Now when a ship is on a wind, her course, we have said, is along a line passing from the lee bow to the weather quarter, which line is also that of the direction in which the ship impinges upon the particles of water. Each particle of water, after its impact with the lee bow, will be reflected from it in a direction which, according to the law of the collision of bodies, will form an angle with the bow, and consequently with a tangent to the bow at the point of impact, and would therefore, if produced to cut the middle line of the ship, form a greater angle with that line than would be formed by this tangent to the bow at the point of impact, produced to cut the same line.

The results do not agree with practice.

Error in the preliminary assumption.

Correction of this error.

This will be the case with the whole of the particles of water which come in contact with the lee bow, and along all that part of the lee side of the ship, a tangent to which, if produced, would meet the line of the ship's course at any finite distance before her bows; so that as a ship progresses along the line of her course, since these motions may all be supposed to become constant, her lee side will pass through water having an absolute motion with respect to the motion of the ship, the direction of which forms an acute angle with the middle line of the ship produced aft.

We will now consider the effect of the accumulation of the water at the bows of the ship, either to diminish or to increase this angle. Since there must be a constant tendency in the particles of water which compose this accumulation to recover their level, there must also be a constant run of particles from the apex of this accumulation to its base; the ultimate direction of the sum of all these motions would therefore evidently form an acute angle with the middle line of the ship produced forward; and consequently, by the composition of forces, the action of the particles of water to recover their level would increase the angle which the direction of the motion of the water makes with the middle line of the ship produced aft.

By extending the same reasoning to the motion of the water on the weather side of the ship, a very little consideration will show that the principal effect the passage of the ship through the water would have on the particles of water on that side, would be to cause them to rush aft in a direction inclined towards the middle line of the ship, in order to fill the vacuum created under the weather quarter by the passage of the vessel along the line of lee-way.

We may therefore assume that the particles of water have a motion at the stern of the vessel, the direction of which forms an acute angle with the middle line of the ship produced aft, which angle will evidently be dependent on the fulness or the fineness of the after-part of the body, and on the angle which the line of the ship's course, or that of the lee-way, makes with the middle line of the ship, consequently the inactive position of the rudder will be when it forms this angle with the middle line of the ship, that is, when the rudder is to leeward, and consequently the helm a-weather. And this position should be the theoretic limit of the degree of weather helm a ship should carry, as in any other position there must be a force acting on the rudder, which must increase the resistance the ship expe-

Experience confirms these views.

riences in her passage through the water. A practical confirmation of the correctness of this principle, and of the fact that this generally advantageous position of the rudder is a-lee of the middle line of the ship, may be drawn from the common observation, that when a ship is in good trim, the helm, being a-weather, has a very perceptible tremulous motion, which must arise from the rudder's being in a position in which it is not acted upon on either side by any constant force. This method of considering the direction of the flow of the water to the rudder considerably diminishes the estimate of the excess of its effect on the lee side of the rudder over that on the weather. But there are several other considerations which operate in increasing the effect of the weather-helm. From the direction in which the water flows past the ship, there will be a much greater reduction of pressure on the weather side of the rudder when the helm is to windward, and therefore a greater positive pressure on its lee side to turn the ship, than will occur under the opposite circumstances, or when the helm is a-lee. Also, the broken and disturbed state of the water on the after-part of the weather side of the ship, and the consequent various degrees of resistance it opposes, must lessen its effect when the helm is a-lee.

Weather helm.

Ships with lee helm leewardly.

Effect mistaken for cause.

It has been said to be proved by practice, that ships which carry lee-helms cannot be weatherly, that is, will fall faster to leeward than those which carry weather helms. But though the fact is correct, the reason assigned is in some degree mistaking the effect for the cause. It has before been said that a part of the force of the wind acts in driving a ship bodily to leeward; of course its effect will be greater or less in proportion to the lateral resistance opposed to it, and the ship which opposes less lateral and greater longitudinal resistance to the water than another, will in the same period of time have fallen farthest to leeward, and the line of her course will have made a larger angle with her middle line, by which the effect of the water on the after-part of the lee side is increased, while that on the fore-part, both of the lee and weather sides, is diminished, and the helm must consequently be kept less a-weather. A practical proof of the correctness of this reasoning may be drawn from the practice of the merchant-vessels, which are generally, from form, more leewardly than men-of-war. They have their fore-mast placed much nearer the centre of the ship than is usual in sharper and finer formed bodies. This has evidently arisen from the operation of the cause above mentioned, which has shown that they require the resultant of the effort of the wind on the sails to be proportionately farther aft to insure their carrying a weather-helm. From this reasoning it is evident that, under some circumstances, it may be the leewardliness of the ship which causes her to carry a lee-helm; and that when such is the case, the defect might be remedied, not only by the usual methods of placing the masts farther aft, and altering the draught of water, but by increasing the lateral resistance by the addition of false keel, or by greater depth in the water.

Disadvantage of lee helm.

There is another disadvantage arising from a ship's carrying a lee-helm, which is, that the action of the water on the weather side of the rudder acts in conjunction with the force of the wind in forcing the ship bodily to leeward; while, on the contrary, when the helm is a-weather, the action of the water on the rudder is in opposition to the force of the wind.

Effect of sail on helm.

Having now pointed out wherein the necessity consists, that a ship should carry a weather helm under all circumstances, and explained the principles by which the position of the helm is governed, it next remains to consider in what manner this position of the rudder may be affected when the ship is under said. This is the more necessary, because there are occasions in which ships that generally carry good helms will carry them a-lee; it therefore also remains to be examined whether this defect might not either be wholly removed, or at least ameliorated.

Ardency.

The ardency of a ship, which is her tendency to fly to the wind, depends, as has been explained, on the relative positions of the resultant of the effort of the wind on the sails, and the resultant of the resistance of the water on the hull. A consideration of the effects produced on these forces, when a ship is under way, will lead to the object of our inquiry.

Passage of a body in a fluid.

Its effect on ardency.

When a body passes through a fluid, it causes an accumulation of the fluid to take place towards its foremost extremity, and a depression of the fluid towards the opposite. The degree of this accumulation and depression will depend on the velocity with which the body passes through the fluid, and its increase must necessarily have a great effect in drawing the position of the resultant of the water farther forward; therefore, from this cause, a ship becomes more ardent as her velocity is increased. Also, as the ship on a wind inclines by the force which communicates motion to her, an increased surface of the bow is immersed; while, from the fulness of its shape both above and below the original water-line, the angle of incidence with which it meets the water does not undergo much alteration: consequently the tendency of the inclination is to draw the resultant of the water forward, in so far as the shape of the bow is involved. By the inclination, the effect of the water on the after upper portion of the lee side is so diminished as to be almost destroyed, in consequence of the decrease of the angle of incidence with which it meets the water, arising from the sharpness of the after-body under the lee quarter, which, by the inclination, is made to approximate to a horizontal plane: consequently the tendency of the inclination is to draw the resultant of the water forward, in so far as the shape of this part of the body is involved. That lower portion of the after-body which is nearly vertical when the ship is upright, and, until the vessel is on a wind, is subjected to little more than the mere friction of the water, immediately that a ship is on a wind offers great lateral resistance, even after the inclination of the ship; and it is this lateral resistance of the after-body which, being brought into action simultaneously with the increased direct resistance of the fore-body, tends to prevent too great an effect from that direct resistance in drawing the resultant of the water forward, and therefore acts in aid of the helm in preventing the ship from flying up into the wind, and thus obviates the necessity of such violent action of the rudder as would be injurious to the velocity of the ship.

Effect of increase of inclination.

The larger the area of this portion of the after-body, the less necessity therefore is there for extreme and consequently detrimental action of the rudder under the circumstances of increased wind and inclination. It appears, however, that in ships generally, the inclination increases the ardency, by drawing the resultant of the water forward.

Of increased immersion of after-body.

This train of reasoning shows us in what the advantage consists which arises from the increased immersion given to the after-extremities of ships; and it enables us to form the following general rule, as an approximation to correctness of principle in determining the increased draught of water to be given to the after-body. The difference in draught of water should increase or diminish in proportion as the area which a ship offers to direct resistance is great or small in relation to the area offered to lateral resistance; or, in general terms, the difference of draught of water in ships, *cæteris paribus*, should vary directly as the ratio which the breadth bears to the length.

Sails assumed to be plane surfaces.

The position of the centre of effort of the wind on the sails is calculated under the supposition that the sails are plane surfaces, and equally disposed with regard to the longitudinal axis of the ship; but when a ship is on a wind, as the force of the wind acts in a direction oblique to the surface of the sails, a greater proportion of the sail is carried to leeward of this axis, and the whole sail assumes a curved surface, the curvature of which increases from the weather to the lee side. From these circumstances, the centre of

Effect of their curvature.

Of increase of wind.

effort is in fact carried gradually farther aft as the action of the wind takes place on the sails. Also, as the force of the wind inclines the ship, the centre of effort of the wind on the sails is carried, by this inclination, over to the lee side, by which, as also by the effect produced on the resultant of the water, which has been before mentioned, the distance between them is farther increased. It therefore appears that, the quantity and disposition of the sail set remaining the same, the ardency will increase as the force of the wind increases, and diminish as that force diminishes; but as it is found in practice that ships very generally require their helms a-lee in light winds, although it is evident that the several circumstances which have been mentioned as creating the tendency of ardency must still exist in a small degree, it would appear that the ardency must increase and decrease in a faster ratio than the force of the wind. Now, as the direct and lateral resistances vary respectively as the squares of the velocities of the ship in these two directions, it is evident that the lateral resistance will diminish in a quicker ratio than the direct resistance, and that, consequently, as the wind decreases, the angle of lee-way, or that of the ship's course, will be increased, which, it has before been proved, will draw the resultant of the water aft, and diminish the ardency; therefore the increase and diminution of the ardency of a ship will be in proportion to the difference of the ratios of increase and decrease of the direct and lateral resistances.

Means of diminishing lee helm.

From the causes which have been assigned for a ship's carrying a lee helm in light winds, it is evident the defect may be lessened by all those means of trimming either the sails or the ship, which have been mentioned as tending to increase the distance of the resultant of the water before the centre of effort of the wind.

Lee helm dependent on state of the sea,

But when a ship's carrying a lee helm is occasioned, as it sometimes is, by the state of the sea, the waves of which, strike the ship on the weather bow, and in their passage cause a great immersion of the lee quarter, any attempt to bring the resultant of the water forward would, from the consequent greater immersion of the bow, and the necessary addition to the momentum, increase the effect of the impulse. The evil may be lessened by diminishing the quantity of head-sail, which will both bring the centre of effort of the wind aft, and diminish the violence of the pitching; and also, if the inclination of the ship were increased, that, by increasing the effect of the water on the lee bow, and diminishing its effect on the lee quarter, might in some cases prove advantageous.

and on the position of the masts.

In heavy weather, ships under a small quantity of sail very generally carry slack helms, partly in consequence of the position of the centre of effort of that sail, and partly owing to the state of the sea. Under these circumstances it is generally impossible to carry enough of after-sail to remedy this defect; and to trim the ship by the head would be only to increase it, on account of augmenting the pitching. There is therefore no other remedy than that which would arise from such an original disposition of the masts as would render the power of creating a balance between the effects of the sails more easy. But here we would observe, that before making any alteration in the position of the masts, great caution is necessary; for possibly one of the first requisites in a ship is, that she should work quickly, which quality depends on the proportion of sail before and abaft the axis of rotation, and not on the position of the centre of effort of the whole surface of the sail. Therefore no alterations can be made in the position of the centre of effort of all the sails, or in the positions of the masts, unless due consideration be given to the effect they would have on these proportions.

Too great ardency.

It may now be necessary to observe, that a ship may, on some occasions, be too ardent. In addition to the alterations which will suggest themselves in this case, from what has been already said, it may be observed, that as the curvature of the sails, and the inclination of the ship, both tend to increase the ardency, it may be diminished by taking in sail, especially those which, from their greater breadth, assume a greater degree of curvature.

Erroneous objections.

It is sometimes objected by practical men, that trimming a ship according to the principles laid down by theory, has not the effect which was to have been expected; but this often arises from an ignorance of the necessary degree of trimming, or from a mistaken notion of the effect which a certain degree will produce. In order, in some measure, to obviate this difficulty, the following table is given. It contains the weight which it will be necessary to move a distance of forty feet, either aft or forward, to produce an alteration of one foot in the trim of a ship. The length and breadth of the ship are given in the table, merely as being more correct data for the comparison of size than the class of the vessel or the number of guns.

| Class of Vessel and number of Guns. | | Length. | Breadth. | Weight to be moved a Distance of Forty Feet. |
|---|---|---|---|---|
| | | Feet. | Feet. | Tons. |
| First rate | 120 | 205·25 | 54·50 | 112 |
| Second do. | 84 | 192·25 | 51·44 | 90 |
| Fourth do. | 60 | 174·00 | 43·67 | 58 |
| Fifth do. | 46 | 159·70 | 40·50 | 38 |
| Sixth do. | 28 | 120·20 | 33·67 | 22 |
| Sloop | 18 | 111·25 | 30·50 | 14 |

If any other alteration in the trim be desired, it may be deduced from the results given in the above table, by a simple proportion. And since the effect produced on the centre of effort of the sails, by taking in or setting any sail, may be estimated in the manner described in the course of these remarks, the alterations necessary to be made in order to produce any desired effect may be easily determined. Another source of error may arise from the various rakes of the masts; from which the angle of incidence, and consequently the force of the wind, which is as some function of the sine of the angle of incidence, varies considerably for the sails of each mast; and if the trim of the ship be altered, there must be a corresponding effect produced in this angle; by which the relative proportions of the force of the wind on the several sails will be altered, as will also its total effect on all the sails.

Bracing of the yards.

Most of the writers on naval architecture have considered the problem of determining the angle which should be formed by the yard with the keel, under the different circumstances of wind. Don Juan, whose highly scientific and thorough practical knowledge entitles his opinions to more than common attention, on a subject in which the researches of theory require to be aided by the deductions from experiment, has determined these angles for a ship of sixty guns, and has also given some general rules to guide any variations from them. When this ship was close-hauled, with all sail set, he found that the angle the yard should make with the keel should be 28° 47′, and with the wind on the quarter, 50° 11′; but when the wind was so high that only a small quantity of canvass could be set, these angles were respectively increased to 40° 42′ and 56° 21′. He also arrives at the general conclusion, "that, the greater the quantity of sail set, the less should be the angle made by the yard with the keel;" and also, as he makes the relation between the direct and lateral resistances enter into his investigations, "the sharper and the more adapted for velocity a vessel is, the smaller should be the angle made by the yard with the keel;" consequently frigates and smaller vessels should, under similar circumstances, have their yards braced sharper than line-of-battle ships; and again, "that the nearer the sails approach to plane surfaces, the less should this angle be."

Erroneous position of fore-mast.

According to the present positions of the masts of a ship, the sails on the fore-mast are generally not capable of being so sharply braced as those on the main-mast; but as theory and practice, as may be instanced in fore-and-aft rigged vessels, concur in fixing the limits to which it would be desirable to brace the yards, within even what can generally be attained on the main-mast, much of the force of the wind on the sails of the fore-mast must be lost; and as this less sharpness of bracing, common for the yards on the fore-mast, is even found to be necessary in many ships, to enable them to carry their helm sufficiently a-weather, it would appear that the position of the fore-mast is too far forward, and that moving it aft would be advantageous; besides the good effect it would have, as has been shown, in diminishing the violence of the pitching motion.

The position of the fore-mast appears to have remained nearly the same as it was determined in the early part of the last century, although many of the reasons which then fixed it at about one ninth the length of the ship from the stem have ceased to exist. Our ships are now longer, and there is consequently room for working the sails, without those of one mast coming in contact with, or destroying the effect of the wind on, those of the other. The after-parts of the hull above water are very considerably reduced, and do not therefore render so great a proportion of head-sail necessary to counterbalance the effect of the wind on them. The bodies of the ships are, from the increase of the dimensions, much finer abaft, and consequently the resultant of the resistance is farther aft. From these considerations, and from the fact that it is found that complaints are made of ships carrying lee helms, it appears not improbable that the generality of our ships would be improved by an alteration in the position of their fore-masts.

Modern English ships approximate in form to the Swedish rather than to the old French form.

The forms of our ships, and indeed those of some of the more modern French vessels of which we are possessed, have approximated more to that recommended by Chapman, and since his time adopted by the Swedes and Danes, than to that of the old French bodies, which were for such a series of years the chief guides of the English ship-builder. The marked characteristics of the old French body were, a flat floor, with a sharp and, beneath the water, hollow fore-part, and a comparatively very full after-part. The character of the Swedish construction is, the rising floor, full fore-body, and extremely fine after-body. The generality of the English ships of the present day are built with the rising floor, and approximating more, towards the extremities, to the Swedish than to the old French characteristics.

Therefore the masts should correspond in position.

It seems therefore but reasonable that the positions of the masts of our ships should partake of the principle which appears to have dictated the alteration in the form of their bodies. With this view, and for a general example as to the positions of ships' masts, and of the ideas of various constructors, the following table has been formed, of the positions of the masts of the vessels contained in Chapman's "large work," of some of the present Swedish ships, of the various classes of English ships, and of several other vessels which have either some peculiarity in this feature of their construction, or are remarkable for an excess of any good or bad quality dependent on it. The other data in the table are necessary for completing the comparisons which may be made.

*Table of the Stations of Masts in Ships.*

| Ships' Names. | No. of Guns. | Length on the Load Water-line. | Distances of the Masts abaft the foremost extremity of the Load Water-line. | | | Ratio of the Distance of the Masts from forward, to the length of the Load Water-line. | | | Ratio of Difference of Draught of Water to the Mean Draught of Water. |
|---|---|---|---|---|---|---|---|---|---|
| | | | Fore-mast. | Main-mast. | Mizen-mast. | Fore-mast. | Main-mast. | Mizen-mast. | |
| | | Feet. | Feet. | Feet. | Feet. | | | | |
| Swedish ships, from Chapman's large work | 110 | 205·2 | 28 8 | 110 5 | 174·0 | ·1398 | ·579 | ·848 | ·094 |
| | 94 | 190·1 | 27·0 | 112·2 | 164·1 | ·1402 | ·590 | ·857 | ·085 |
| | 80 | 182·1 | 25·7 | 105·5 | 154·2 | ·1402 | ·578 | ·845 | ·089 |
| | 74 | 177 9 | 24·8 | 102·7 | 150·5 | ·1398 | ·578 | ·848 | ·083 |
| | 66 | 174·0 | 24·3 | 100·0 | 148·0 | ·1400 | ·570 | ·844 | ·082 |
| | 52 | 164·1 | 22·9 | 93·2 | 138·4 | ·1390 | ·569 | ·845 | ·103 |
| | 40 | 149·6 | 23·3 | 86·5 | 125·2 | ·1570[1] | ·580 | ·840 | ·100 |
| | 32 | 125·3 | 19·5 | 72·5 | 104·4 | ·1560[1] | ·678 | ·831 | ·093 |
| | 20 | 113 6 | 17·5 | 65·6 | 94·5 | ·1540[1] | ·576 | ·837 | ·142 |
| Carl XIII., Swedish | 80 | 177·9 | 24·3 | 102·0 | 148·0 | ·1380 | ·576 | ·858 | ·108 |
| Corvette, Swedish | 20 | 108·5 | 15·0 | 61·7 | 90·8 | ·1440 | ·570 | ·835 | ·120 |
| The Chapman, Swedish | ... | 149·0 | 20·0 | 89·5 | 124·2 | ·187[2] | ·596 | ·835 | ·000[3] |
| President, French | 46 | 159·5 | 24·0 | 87·5 | 132·2 | ·150 | ·550 | ·831 | ... |
| Do. altered to the Piedmontaise | 40 | 159·5 | 21·0 | 87·5 | 132·2 | ·132 | ·550 | ·831 | ... |
| Comet, bomb | ... | 109 0 | 13·4 | 61·7 | 90·5 | ·123 | ·565 | ·831 | ·000[3] |
| Do. as altered | ... | 109·0 | 17·4 | 61 7 | 90·5 | ·162 | ·565 | ·831 | ... |
| Pearl, Mr Sainty | 10 | 114·7 | 18·7 | 64·0 | 97·4 | ·163 | ·557 | ·850 | ... |
| Do. altered by his request | 16 | 114·7 | 16·7 | 66·5 | 99·4 | ·103 | ·577 | ·863 | ... |
| Caledonia | 120 | 205·25 | 25·0 | 113·0 | 171·7 | ·122 | ·552 | ·835 | ·057 |
| Asia | 84 | 192 25 | 22·3 | 109·0 | 160 2 | ·110 | ·568 | ·832 | ·053 |
| Southampton | 60 | 174·0 | 20·7 | 97 2 | 146·7 | ·119 | ·560 | ·845 | ·048 |
| Seringapatam | 40 | 159·7 | 21·2 | 85·0 | 132·3 | ·133 | ·535 | ·832 | ·070 |
| Leda | 48 | 151·0 | 19·0 | 85·3 | 128·7 | ·124 | ·565 | ·854 | ·089 |
| Euryalus | 42 | 146·0 | 17·7 | 82·2 | 123·8 | ·124 | ·563 | ·848 | ·104 |
| Sapphire | 28 | 120·2 | 14·7 | 68·7 | 102 4 | ·122 | ·568 | ·850 | ·066 |
| Orestes | 10 | 111·25 | 14·5 | 04 7 | 97·4 | ·129 | ·573 | ·864 | ·060 |
| Queen | 110 | 202·2 | 24·33 | 118·0 | 175·84 | ·121 | ·583 | ·870 | ·085 |
| Vanguard | 80 | 108·2 | 25·7 | 110 9 | 104·3 | ·137 | ·584 | ·823 | ... |
| Vernon | 52 | 176·7 | 27·6 | 104·5 | 154·7 | ·156 | ·590 | ·874 | ... |
| Pique | 36 | 160·6 | 23·5 | 94·4 | 139·5 | ·146 | ·587 | ·867 | ... |
| Vestal | 26 | 131·0 | 20 3 | 77·3 | 114·6 | ·155 | ·590 | ·874 | ... |
| Rover | 16 | 109·5 | 15·1 | 04·8 | 96·2 | ·138 | ·590 | ·874 | ... |
| Inconstant | 36 | 160·0 | 20·0 | 90·33 | 138·0 | ·125 | ·564 | ·860 | ... |
| 465 tons, Merchant-ships. | ... | 115·0 | 16·6 | 65·0 | 99·2 | ·143 | ·565 | ·861 | ... |
| 450 tons | ... | 116·6 | 16·6 | 66·0 | 98·0 | ·144 | ·570 | ·840 | ... |
| 435 tons | ... | 114·8 | 16·2 | 67·1 | 96·4 | ·142 | ·584 | ·840 | ... |
| 400 tons | ... | 106·5 | 16·9 | 66·2 | 92·7 | ·166 | ·610 | ·850 | ... |

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[1] An increase in the rakes of the stems.

[2] The fore-mast raked four inches in ten feet.

[3] On an even keel.

Theory.

Position of masts in merchant-ships.

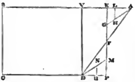
From this table it will be seen that the position of the fore-mast in the ships of different rates in her majesty's service is considerably more forward than in the Swedish ships; and that in Chapman's experimental frigate, the Chapman, it is remarkably far aft. The Comet, as altered, after being sold out of the service, the Pearl, built by Mr Sainty, and the four merchantmen, are proofs of the practice, before alluded to, of the merchant builders; the alteration in the position of the masts of the Comet having taken place under the direction of the late Mr Fearnall, a gentleman of high character for a knowledge of his profession.

The stations of the masts in the ships built after the designs of the present surveyor of the navy, Sir William Symonds, approximate very nearly to those of the Swedish ships; the main and mizen masts are even rather farther aft in proportion to the length of the ship.

Correct point from which to measure the positions of the masts.

The positions of the masts are given, in the table, in relation to the foreside of the rabbet of the stem; but though this point has been adopted in compliance with the usually received custom, and to avoid the introduction of a feature which might have rendered comparisons more difficult, a more correct method would be to estimate the station of the masts from a point K (fig. 5), at a distance AK from the foremost extremity of the load water-line; such that, KP being drawn perpendicular to the load water-line, it shall intersect AD, the foremost boundary of the longitudinal vertical section of the vessel, in such a manner that the resistance to angular motion round an axis of rotation BC, passing through the centre of gravity of the vessel, shall be equal to the triangles AKF and DFP, DP being the lower boundary of the false keel produced.

Fig. 5.



The point K being determined for all ships, comparisons might be correctly made of the positions of the masts in vessels with the most dissimilar rakes of the stem; which feature, from its effect on the resultant of the resistance, must have a considerable influence on the positions of the masts, and which cannot be estimated in distances measured from any other point.

The following proof will show, that if BK be taken equal to the arithmetical mean between BA and CD, the point K will be determined sufficiently correctly for all practical purposes.

From D (fig 5) draw DV perpendicular to AB. Bisect KF and FP in G and M, and draw AG and DM. Take AH $= \frac{2}{3}$AG, and DN $= \frac{2}{3}$DM; then H and N will be the respective centres of gravity of the triangles AKF and DPF. From H and N draw HL and NO perpendicular to BA and CP. Let AB $= a$, CD $= b$, AV $= a - b = c$, AK $= x$, AL $= \frac{2}{3}x$, and VD $= h$. Then the resistance to rotation of the triangle AKF is proportional to the

$$\text{area AKF} \times \text{BL} = \frac{\text{AK} \cdot \text{KF}}{2} \cdot \text{BL}.$$

$$\text{Now, AK : KF :: AV : VD} \therefore \text{KF} = \frac{hx}{c}$$

$$\text{the resistance} = \frac{hx^2}{2c} \cdot \left(a - \frac{2x}{3}\right).$$

And in the same manner, the resistance of DFP is

$$= \text{area DFP} \cdot \text{CO} = \frac{\text{DP} \times \text{PF}}{2} \cdot \text{CO},$$

$$\text{PF : DP :: DV : AV} \therefore \text{PF} = \frac{h \cdot \overline{c - x}}{c}.$$

Theory.

$$\text{Hence the resistance} = \frac{h \cdot \overline{c - x}|^2}{2c} \cdot \left(b + \frac{2}{3}\overline{c - x}\right),$$ and these resistances must be equal to each other,

$$\therefore x^2\left(a - \frac{2x}{3}\right) = \overline{c - x}|^2\left(b + \frac{2}{3}\overline{c - x}\right)$$

$$\text{and } x = a - \sqrt{a^2 - \left(bc + \frac{2c^2}{3}\right)};$$

from which expression, if numbers be substituted for the several quantities, it would be seen that, assuming BK equal to the arithmetic mean between AB and CD, will be sufficiently correct.

Recapitulation.

The method of finding the horizontal distance of the centre of effort of the sails, either before or abaft the centre of gravity of the ship, has now been explained as being a necessary element to be determined in forming the design of a vessel. The effect which the action of the water on the hull, and of the wind on the sails, would have, under various circumstances, on the relative positions of this point with respect to the centre of gravity of the ship, has been described, and also the necessity of regulating the trim of the ship and sails according to the state of the sea and wind, that the most advantageous proportionate distance may be preserved between them.

Height of effort of sails.

We shall now investigate the principles on which the determination of the vertical height of the centre of effort of the sails above the centre of gravity of the ship depends. This problem, though it is one which may be classed among those of which the "solution resolves itself to laws of nature which are yet imperfectly developed," may be solved by induction from experiment; and we shall show that sufficient data may by this means be obtained, to render the abstract principles of science, on which it depends, practically available, so as to overcome the difficulties which at present oppose themselves to the perfecting one of the most important elements of naval architecture, the sizes and proportions of the masts and yards.

Moment to resist inclination.

In describing the circumstances attendant on the inclination of a ship from the upright position, we have said that the moment of the force exerted by the vertical pressure to resist the inclination will be measured by the perpendicular distance from the centre of gravity to the direction of the resultant of the vertical upward pressure of the water after the inclination, which necessarily passes through the centre of gravity of the displacement. We have hitherto called this the moment of stability, but it may be more properly termed the moment of hydrostatical stability, as being dependent on the laws of the equilibrium of fluids. But if the force which has been described as inclining the ship round its centre of gravity also communicates motion to the system, another moment of stability will be generated by the resistance which the water opposes to the motion. This resistance, as has been before explained, may be supposed to act in a resultant, the direction of which will necessarily depend on the form of the vessel. Now, if the form be such that the direction of this resultant will pass above the centre of gravity of the ship, its moment, estimated from that centre of gravity, will act in conjunction with the moment of hydrostatical stability before described, and will diminish the inclination; a contrary effect will ensue if this resultant passes below the centre of gravity. Now, if the moment of this force to diminish the inclination were equal to the moment of the force which acts to produce it, the ship would remain in a vertical position; but if it be not equal to it, the inclination will be caused by the action of the excess of the moment of the inclining force over the moment of the force acting to diminish the inclination, and the ship will revolve until this part of the inclining force shall be destroyed by the moment of hydrostatical stability which will be generated by the inclination. The moment of sta-

Hydrostatical stability.

Hydrodynamical stability.

bility resulting from this cause may be called the moment of hydrodynamical stability, as being dependent on the motion of the body in the fluid, that is, on the relative motion of the fluid. This does not agree with the usual definition of hydrodynamical stability adopted by writers on naval architecture, as that also involves the elements of the hydrostatical stability in its terms; but it is thought that keeping each moment of stability distinct, by referring it wholly to its own generators, tends to simplify the consideration of them; and also, the explanation of the principles on which the height of the centre of effort of the sails depends may by the same means be divested of some obscurity.

Equilibrium of wind on sails, and water on hull.

Now, when, by the action of the wind on the sails, motion is communicated to a vessel from a state of rest, at first the effort of the wind on the sails is much greater than that of the water on the hull, and by the effect of the excess the velocity of the vessel is accelerated: but the velocity with which the wind acts on the sails is diminished in proportion as the velocity of the vessel is increased, therefore also the force with which it acts on them is gradually lessened; but as the velocity of the vessel increases, the resistance the water opposes to its motion is also increased; consequently the two forces, the effort of the wind on the sails, and the resistance of the water on the hull, will ultimately become equal to each other; and as they act in opposite directions, the vessel will, by the laws of motion, continue to move uniformly in the direction of its course with the last acquired velocity; and this velocity will be in proportion to the moving force, that is, to the force of the wind and the area of sail exposed to its action, or, if the force of the wind be supposed constant, will be in proportion to the area of the sail.

Uniform motion of the vessel.

Limit to height of centre of effort.

From what has been before said, it is evident that the moment of sail must be in proportion to the stability of the ship; and since the velocity will be in proportion to the area of sail exposed to the action of the wind, the height of the centre of effort of the sail should be determined from the consideration of acquiring the greatest effective area of sail of which the powers of the ship will admit.

Point vélique.

Not practically applicable in oblique courses.

Bouguer, from reasoning on the facts which have been explained, which are, that when a ship has acquired an uniform velocity in any direction, the action of the wind on the sails to propel her in that direction becomes equal to the resistance opposed to her motion by the water, and that the moment of the resistance, calculated from the centre of gravity or of rotation, that is, the moment of hydrodynamical stability, subtracted from the moment of the action of the wind on the sails, estimated from the same point, will give the force by which the ship is inclined, conceived the idea that the sails of a vessel might be so disposed that she should maintain the same vertical position when under sail as when at anchor. This he proposed to effect by adjusting the sail in such a manner that its centre of effort should be situated in a point, which he has named the "*point vélique*," and which he describes as being such, that when the centre of effort of the sails coincides with this point, the moment of the force of the wind to incline the ship will be wholly destroyed by the moment of hydrodynamical stability. But such an arrangement of the sail is not practically applicable to the cases in which the direction of the action of the force of the wind is oblique to that of the course of the vessel; for, from the small proportion which the breadth of a vessel bears to her length, the moment of hydrodynamical stability will, under these circumstances, be less than when the directions of the wind and of the ship's course coincide, while the resultant of the effort of the wind will act at the same height above the centre of gravity of the ship in either case; therefore Bouguer only insists, that since the moment of the hydrodynamical stability cannot, consistently with other circumstances, be made to destroy the whole of the effort of the wind to incline the ship, care should be taken that these two forces should be so proportioned to each other, that a sufficient moment of hydrostatical stability may be acquired to resist the excess of the moment of the wind on the sails over the moment of hydrodynamical stability, without too great an inclination of the ship.

Of importance in direct courses.

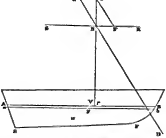
But when the direction of the wind coincides with that of the course of the vessel, it is of great importance that the change from a state of rest to one of motion, or rather from one velocity to another, should be performed without any longitudinal inclination towards either extremity, and that the vessel should preserve that seat in the water which has been determined as most advantageous with reference to the longitudinal position of the centre of effort of the sails.

Bouguer reasons on false premises, yet valuable.

The course of reasoning which Bouguer has pursued to determine the position of this point involves suppositions which are at variance with the facts attendant on a vessel's motion through the water, and therefore the conclusion at which he arrives is erroneous; still, as an elucidation of the principle, his method may be advantageously explained.

Investigation of position of point vélique.

Fig. 6.



He supposes DH (fig. 6) to be the direction of the resultant of the direct and vertical resistances experienced by the fore-part of the vessel AEFB, moving in the direction AB; and the line SK to be the direction of the resultant of the whole force of the wind acting on the sails. Let it meet DH in N. Now since, when the ship has acquired an uniform velocity, the forces which oppose the motion are equal to those which produce it, and as these forces act horizontally and destroy each other, the forces which remain must be vertical. Take NR and NP to represent in quantity and direction the force of the water on the bows, and of the wind on the sails; then complete the parallelogram NRTP, and join NT; NT will represent, in quantity and direction, the force remaining after those parts of the forces NR and NP, which are equal and opposite, are destroyed; and therefore NT will act in a vertical direction to lift the ship. But though this will be the direction of the action of NT on the vessel, its effects may also be to produce a rotatory motion round her centre of gravity. This will depend on the position of the point N, the intersection of SK and DH. If we suppose the direction DH to be constant in position, and SK to vary in position according to the height of the sails, we shall see, that when the masts and sails are high, the direction SK will cut the direction DH at a point near the stern; and therefore the action of the force NT taking place so near one extremity of the vessel, and one side of the centre of gravity, will tend to immerse the opposite extremity. On the contrary, if the masts and sails are low, the direction SK will intersect the direction DH more near to the bows of the ship, and the action of NT being before the centre of gravity, will raise the fore and immerse the after part; and this in-

Theory.

clination will continue until the force which causes it is destroyed by the moment of the hydrostatical stability generated by the inclination. From this, Bouguer concludes that it is only when the masting is of such a height that the direction SK intersects DH at a point at some mean distance between the bows and stern, and at which neither of these effects will be produced, that the ship will have no tendency to longitudinal oscillation, and the only effect of the force NT will be to lessen the part of the ship which is immersed in the water when she is at rest; and this point he has called the *point velique*. Bouguer determines the position of this *point velique* in the following manner. From *r*, the centre of gravity of the load water-section, as being nearly coincident with the centre of gravity of the lamina, AB*ba*, of the vessel which is lifted by the action of the force NT, the vertical line VT is drawn, and the point N in which it intersects the direction of the resultant of the resistance of the water to the bows will be the point through which the horizontal line SK, representing the direction of the action of the wind on the sails, should pass, in order that the ship may move in the direction of its course without a depression of either extremity. In order to prove that this will be the case, he supposes the displacement ABFE of the ship to be made up of the two homogeneous parts AB*ba* and *ab*FE; and therefore, when the ship is only subjected to the vertical pressure upwards of the fluid, these parts will have their common centre of gravity, which will be the centre of gravity of the displacement, in the same vertical plane with the centre of gravity of the ship. The horizontal distances of *r* and *w*, the centres of gravity of the homogeneous parts AB*ba* and *ab*FE, from the vertical section in which the centres of gravity of the ship and of the displacement are, will be inversely as those parts; but when, by the action of the force NT at *r*, the displacement is diminished by the quantity AB*ba*, the vertical pressure upwards will be diminished by that same quantity, and will act at *w*, the centre of gravity of the new displacement *ab*FE, with a force equal to the weight of *ab*FE; therefore, the forces being inversely proportionate to the distances of their action from the common centre of gravity of the ship, and both acting upwards in a vertical direction, will maintain the ship in equilibrio round that centre of gravity. This reasoning of Bouguer on the position of the point N is incorrect in its application to practice. It depends on the supposition, that when by the force of the wind motion is communicated to the vessel, she will rise in the water from the effect of the action of the force NT, and the water-line AB will become *ab*, the displacement being diminished by the quantity AB*ab*. It is not enough to satisfy the conditions of Bouguer's reasoning, that NT should exert an effort at *r* equal to diminishing the displacement by the quantity AB*ba*; for unless the diminution of the displacement actually takes place, the position of its centre of gravity cannot be affected in the manner assumed in the reasoning, but will continue in the vertical section passing through the centre of gravity of the ship; and then, by the action of the force NT at *r*, the ship will revolve round the centre of gravity *g*, until, by the motion of the centre of gravity of the displacement, incidental to the revolution, a moment of hydrostatical stability is generated equal to the moment of NT to incline the ship. Now it is proved from experiment that the displacement is actually greater when a ship is in motion than when she is at rest; therefore, reasoning on the supposition of its diminution is inapplicable to practice. There would be an alteration in the position of the centre of gravity of the displacement resulting from this increase, which might either act in opposition to, or with the effect of NT, to incline the ship, according to the relative form of the body above the original water-line.

The error of Bouguer.

But it is evident that the principal error made by Bouguer throughout the investigation of the position of his *point velique* is, that it is conducted with reference only to the resultant of the positive resistances which the vessel experiences, instead of to the resultant of both positive and negative resistances. Chapman, while he adopts Bouguer's views on the existence of some limit to the situation of the centre of effort of the sails above the centre of gravity of the ship, has avoided this error, and has investigated its position from the data of the total resistance experienced by the ship. He first determines the quantity and direction of the mean resultant of both the positive and negative resistances of the water; then, since the force of the wind must be equal to the resistance of the water opposed to it, if the directions of the resultants of these two forces were exactly opposed to each other, their moments, estimated from the centre of gravity of the ship, would be equal, and consequently the force of the wind would have no effect in making the ship revolve round its centre of gravity; therefore, if the surface of the sail was perpendicular to the resultant of the direct and vertical resistances experienced by the ship, there would be no limit, arising from these considerations, to the height at which the centre of effort of the sails might be placed; for, whatever might be its position in the line of direction of the resultant of the resistances of the water, the moments, estimated from the centre of gravity of the ship, would be constantly equal, since the perpendicular distance between that point and the directions of the actions of the forces would remain constant, however the force of the wind, and consequently the resistance of the water, might be increased or diminished. But since the directions of the wind and of the course of the vessel are both horizontal, and the sails are placed nearly at right angles to the horizon, the action of the force of the wind, and its moment round the centre of gravity of the ship, to counteract the moment of the resistance of the water, must be estimated in a horizontal direction; and consequently the height of the centre of effort of the wind on the sails must be measured on a vertical line drawn from the centre of gravity of the ship, and must be such that the horizontal moment of the wind shall be equal to its moment, estimated under the supposition that its action is in a direction opposed to that of the resultant of the resistances of the water, when it will have no tendency to depress either extremity of the vessel.

Theory.

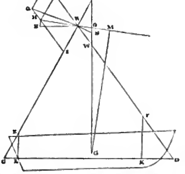
He neglects the negative resistances.

Chapman has avoided the error of Bouguer.

Chapman's investigation.

Chapman's investigation is as follows: Suppose DF and EC (fig. 7) to represent respectively, both in quantity and direction, the resultants of the direct and vertical resistances against the fore and after parts of the vessel. Produce

Fig. 7.



$DF$ and $CE$ to intersect each other in $B$; then on $DB$ produced take $BV = DF$, and on $BC$ take $BI = EC$; complete the parallelogram VBIH, and BH will represent, in quantity and direction, the resultant of the whole of the direct and vertical resistances against the fore and after parts of the ship; and BH, multiplied into GM, GM being drawn from the centre of gravity G of the ship, perpendicular to BH produced, will represent its moment to make the ship revolve round its centre of gravity. The centre of effort of the sails must therefore be at such a height that the moment of the wind, estimated from the centre of gravity of the ship, may be equal to this moment. If HM represent the line of direction of the effort of the wind on the sails, the force of the wind acting in that direction will be represented in quantity by HB; but as the action of the wind is horizontal, and is equal to the horizontal effort of the water, if BH be resolved into BN and NH, then BN represents, in quantity and direction, the horizontal resistance of the water, and NB in the same manner represents the horizontal effort of the wind; and if GO be drawn from G perpendicular to the horizon, meeting HB in O, we have, from similar triangles, HBN and OGM, $NB \times GO = HB \times GM$; that is, O, the point in which a vertical line passing through the centre of gravity of the ship intersects the direction of the resultant of the resistances of the water against the fore and after parts of the ship, is the correct height at which the centre of effort of the sails should be placed, that the ship's horizontal water-line, when she has acquired an uniform velocity, may not be affected by any change in the force of the wind.

The point found by Chapman not the *point velique.*

This point O does not fulfil the conditions of Bouguer's *point velique*, as it only determines the position of the centre of effort of the sail as to height above the centre of gravity of the ship; for the moment of sail acting in a horizontal direction, estimated above that centre of gravity, will be the same at whatever point in a horizontal line passing through O the centre of effort may be placed; therefore this point O may be more properly called the height of sail. The position of the centre of effort of the sails in a horizontal line at this height of sail, will depend on the considerations which have been explained in a former part of this article. It may therefore differ very considerably from that determined by Bouguer, not only in its vertical, but in its horizontal position.

From this investigation of Chapman's, it evidently appears, that unless BH coincides with NB, that is, unless the resultant of the resistances of the water is horizontal, there will be a force NH or HN acting in a vertical direction, either upwards or downwards, at the centre of gravity of the ship, according as the positive or negative vertical resistances are the greater; for this force, acting in a vertical direction, cannot be derived from the direct resistances, which act horizontally; and since the whole force of the wind acts in a horizontal direction, and is destroyed by the horizontal effort of the water, no part of its force can be employed in a vertical direction affecting the action of HN or NH. This force will therefore act to increase or diminish the displacement of the ship when in motion, according as the negative or positive vertical resistances are the greater, that is, the quantity by which the displacement would be increased by the diminution of the vertical pressure upwards, incidental to the motion of the vessel, will be diminished by the action of the force NH; but unless NH is greater than the diminution of the vertical pressure upwards, it will have no effect on the position of the centre of gravity of the displacement, and therefore none on the longitudinal inclination of the ship. The force HN, acting in conjunction with the diminution of the vertical pressure upwards, will affect the position of the centre of gravity of the displacement in the same manner as that affects it, that is, dependent on the relative form of the body above the water. Therefore in this case the ship may have a slight tendency to longitudinal oscillation, even though the centre of effort of the sails be placed at the height of sail, as determined by Chapman; but this will not affect the correctness of Chapman's principle, and a ship may be easily constructed with such a form at the parts about the surface of the water, that this inconvenience will not occur.

Case in which longitudinal oscillation may ensue.

Now, if we suppose BV and BI to be given in position, the force NH or HN will depend, in quantity and direction, on the proportion between BV and BI, that is, on the proportion of DF to EC. Now when BH coincides with NB, or when the direction BH of the resultant of the water is horizontal, the force NH or HN vanishes; therefore, if we suppose HB to coincide with BN, then HB is parallel to CD; and the angle VBH will be equal to the angle BDC, and the angle BCD will equal the angle $HBC = VHB$. Now $VH : VB :: \sin. VBH : \sin. VHB :: \sin. BDC : \sin. BCD$; and since $VH = BI = EC$, and $BV = DF$, therefore $EC : DF :: \sin. BDC : \sin. BCD$; consequently we have, that the positive and negative vertical resistances are equal to one another, and the direction of the resultant of the resistances of the water will be horizontal, when the resultant of the direct and vertical resistances of the water on the bows of the vessel is to the resultant of the direct and vertical resistances on the stern, inversely as the sines of the angles which the respective directions of these resultants make with a horizontal line.

General theorem.

The extremities of a vessel of the usual form may, for the purpose of determining the proportion between the direct and vertical resistances which they experience, be considered as planes moving obliquely in a fluid, and consequently the proportions between the direct and vertical resistances will depend on the angles of inclination which the surfaces of these extremities make with the direction of the vessel's motion, that is, with a horizontal line; and the sum of the direct resistances on either extremity will be to the sum of the vertical as the cosine to the sine of the angle of inclination; consequently, as long as the inclinations of the bow and stern to a horizontal line remain unchanged, this proportion between the direct and vertical resistances experienced by those parts respectively, that is, the proportion of DK to KF, and of LC to EL, will be invariable; and therefore, as far as these considerations are involved, the directions of the resultants DF and EC will remain constant, whatever alteration may take place in their relative proportion to each other, arising from any increase or diminution in the velocity of the vessel.

Proportion between direct and vertical resistances invariable.

Since, when the direction of the resultant of the water is horizontal, $EC : DF :: \sin. BDC : \sin. BCD$, then $EC \cdot \sin. BCD = DF \cdot \sin. BDC$; now let us suppose the proportion of DF to EC to be altered, so that $EC \cdot \sin. BCD$ will be greater than $DF \cdot \sin. BDC$, that is, let us suppose the comparative proportion of DF to EC to be increased.

Produce DV to P, and make BP to BI in the increased proportion of DF to EC, complete the parallelogram BPQI, and draw the diagonal BQ; BQ will represent the direction of the resultant of the resistance of the water, after the alteration of the proportion between DF and EC.

Produce QB to S, then the angle $PBQ =$ the angle DBS, and since BP is parallel to IQ, the angle PBQ is equal to the angle IQB, and the angle IHB is greater than the angle IQB; consequently the angle DBM, which is equal to the angle IHB, is greater than the angle IQB, that is, the angle DBM is greater than the angle DBS, and S, the point in which the direction QB cuts the vertical line GO, will be within or below the point O; therefore GS will be less than GO. If EC, that is, BI, had been increased in proportion to DF or BV, the point S would, in the same manner, have been found to be above the point O; consequently, from this we may deduce the following

General theorem.

Limits to the position of the height of sail.

What governs its height between these limits.

general proposition, that as the proportion which the resultant of the direct and vertical resistances on the bows of a vessel, bears to the resultant of those resistances on the stern, is greater than the proportion which the sine of the angle made by the resultant of the after-resistances with a horizontal line, bears to the sine of the angle made by the resultant of the fore-resistances with a horizontal line, the height of sail will be diminished, and as this proportion is diminished, the height of sail will be increased. Now when DF is infinite in comparison with EC, that is, when the negative resistances vanish, BQ will coincide with BP, and the height of sail will be at W, the point in which the vertical line drawn from the centre of gravity of the ship intersects the direction of the resultant of the positive resistances. But if DF vanishes in comparison with EC, BQ will coincide with BI, and the height of sail will be at R, the point in which the vertical line drawn from the centre of gravity intersects the line BC; consequently the points R and W will be the limits between which the position of the height of sail must be situated. The directions of the resultants of the resistances on the bow and stern being known, the position of this point within these limits will depend upon the velocity of the ship, in as far as that velocity affects the ratio which these resultants bear to each other. And since the negative resistance depends on the degree of vacuum which the vessel creates by the velocity of its passage through the water, it will evidently be very inconsiderable as long as the velocity continues small. In fact, this is found to be the case experimentally, as is also that, after certain limits, this negative resistance increases in a greater ratio than the velocity. We may therefore draw the general conclusion, that the less the velocity of the ship is, the nearer will the height of sail approximate to that of its lowest limit; and, on the contrary, the greater the velocity of the ship, the nearer will this point approach its highest limit. But as we are not yet sufficiently acquainted with the laws of the motion of fluids to determine the ratio of the increase or decrease of the positive and negative resistances experienced by bodies in their passage through the water, we cannot ascertain how near the ultimate position of the height of sail with the greatest velocity which the vessel can acquire will approximate to the limit which has been assigned to it.

Apparent water-line and true water-line.

Effect of accumulation and depression of the water.

One circumstance which may affect the height of sail remains to be noticed; this is, the deviation of the apparent water-line of the ship when she is in motion, from her horizontal water-line, which is occasioned by the accumulation of fluid at the fore-part of the ship, and the depression of it at the after-part, that is incidental to the motion of a body on a fluid. This will vary in degree in proportion to the velocity of the ship. Now if this addition to the one and diminution from the other of the resisting surfaces alter the proportions between their respective vertical and direct resistances, the directions of the resultants of the resistances on these surfaces, which depend on these proportions, will also be altered. If the extremities of the vessel were formed by plane surfaces, neither the accumulation nor the depression would alter the directions of the resultants of the resistances, since the angles of incidence would be the same for every part of the surfaces; but as the extremities of the vessel are curved surfaces, the effect produced on the direction of the resultants of their respective resistances will depend on the relative inclination to the horizon of the curve of that part of the body beneath the horizontal water-line, and of the parts above or below the water-line, which will be affected by the accumulation and depression of the water. Since the lower parts of the vessel's body, both forward and abaft, are those which are generally most inclined to the horizon, it is probable that the direction of the resultant of the resistances on the bow is lowered by the accumulation of the water against them, and that the direction of the resultant of the resistances to the stern is rather raised by the depression of the water at that part. At the same time it must also be observed, that, by the effect of the accumulation, the centre of effort at which the resultant of the resistances against the bows acts will be raised, while, by the effect of the depression, that at the stern will be lowered.

The position of this point will determine the height above the centre of gravity of the ship, at which the common centre of effort of the sails should be placed, not only when the directions of the wind and of the ship's course coincide with each other, but also whatever may be the direction of the ship's course with regard to that of the wind; for, under all circumstances, that portion of the force of the wind which acts in propelling the ship in the direction of her course, will be subject to the same laws which govern the action of the whole force of the wind when it acts in that direction.

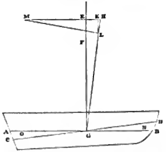
Addition or diminution.

It is also evident, that it is not only necessary that the centre of effort of the surface of those sails which are usually set, and for which the position of the height of sail is generally recommended to be estimated, should coincide with this point; but also, that when additions are made to the quantity of sail set, care should be taken to preserve the common centre of effort of the whole surface as nearly at this same height above the centre of gravity of the ship as is possible.

Velocity may not increase with increase of sail.

It is frequently observed that a ship's velocity does not increase or decrease in proportion to the additional quantity of sail set or taken in. It is evident, from the principles which have been explained, that these apparent anomalies must arise from the mal-position of the centre of effort of the sail; and, in fact, it is even possible that the velocity of a ship may be decreased by the addition and increased by the diminution of sail, if the centre of effort is improperly placed. That this may be the more evident, suppose AB (fig. 8) to be the water-line of a ship, when the centre of effort of the sails is situated at the correct height of sail GF; then suppose the disposition of the sails to be so altered that their centre of effort coincides with E, a point situated above the point F; and let o = the force of the wind on the sails both before and after the alteration; its moment to turn the ship round its centre of gravity G, when its action takes place at the point E, will be equal to $a \cdot EG$, and this force will be opposed by the horizontal resistance of the water, also $= a$, acting at the distance FG from the centre of gravity G; therefore $a \cdot EG - a \cdot FG = a \cdot EF$ will be the force exerted by the wind to make the ship revolve round G, its centre of gravity, and immerse the bows; and the inclination will continue from the effect of this action until the moment of hydrostatical stability, which it will generate, becomes sufficient to counteract it. It should

Fig. 8.



here be observed, that by the difference which the inclination of the ship will make in the angles of incidence of the water on the bows and stern, the correct height of sail, after the inclination, will most probably not coincide with F, but the alteration arising from this circumstance in the position of this point will depend on the form of the vessel's body.

When the force $a \cdot EF$ is destroyed, suppose the water-line to coincide with CD, then from G draw GH, making with GE the angle EGH equal to the angle of inclination DGB; take GH = GE, then H will be the position of the centre of effort E of the sail after the inclination, and the angle BGH will represent the inclination of the plane of the sails to the horizon, they having been supposed to be vertical before the inclination of the ship. Now from H draw HM horizontal, and take MH to represent the whole force of the wind acting in that direction, at the points H and F; then from M draw ML perpendicular to GH; and from L draw LK perpendicular to MH; MK will represent the horizontal force of the wind acting to propel the ship in the direction of its course, when the centre of effort of the sails is at E. Since MH represents the quantity of this force when the centre of effort of the sails is at the true height of sail F, KH will represent that part of the horizontal force which is lost by the mal-position of the centre of effort; and if MH, the whole force of the wind, be assumed equal to radius, then from similar triangles MHL, LHK, we get the value of KH equal to the square of the sine of the angle of inclination divided by the radius, when radius is equal to the whole force of the wind. Therefore, if the removal of the centre of effort from its correct position at the height F had been accomplished by an addition to the quantity of sail set, instead of by an alteration in its disposition, unless the increase of MH, the force of the wind arising from the increase in the area of sail set, was greater than this value of KH, which represents the force lost, the velocity must be diminished instead of being increased, by the addition to the force of the wind; since its effective force to propel the ship would be diminished by a quantity equal to the difference between this value of KH and the increase of the whole force of the wind. Now suppose that by the mal-position of the centre of effort at E, the ship is inclined so that GH is the plane of the sails, it is evident that the quantity of sail may be reduced until the force of the wind is diminished by a quantity equal to $\frac{\text{sin.}^2\ EGH}{\text{rad.}\ MH}$, without diminishing the velocity, if, by this reduction in the quantity of sail, the centre of effort is removed to its correct position at F. This reasoning shows that when the centre of effort of sail is placed too high above the centre of gravity of the ship, the disadvantages of such an adjustment may be lessened by raking the masts, since by that means the loss in the force of the wind may be avoided.

If centre of effort of sail be above height of sail.

When the centre of effort is above the height of sail, the velocity of the ship will be subject to further decrease from the increase of resistance which will result from the immersion of the full parts of the body forward, and the consequently greater area of midship section. Also, in the case which has been supposed of the plane of the sails being vertical before the commencement of the action of the wind, when the longitudinal inclination EGH takes place, a part of the action of the force KL will act to increase the displacement, and consequently the resistance. This disadvantage may also be diminished by raking the masts.

Excess of moment of sail over moment of hydrodynamical stability.

There are other circumstances arising out of the longitudinal inclination of the ship, caused by the excess of the moment of the wind on the sails over the moment of hydrodynamical stability, which are disadvantageous to the good properties of the ship. The equilibrium which ensues between the excess of the moment of the wind and the moment of hydrostatical stability, which has been described as being generated by the inclination, will not be constant, as every increase or decrease in the force of the wind will cause an increase or decrease in the moment of stability, which must be obtained by a corresponding change in the inclination; therefore a ship in which the centre of effort is placed above the true height of sail, will be subject to an alteration in her water-line at every change in the force of the wind; and it will, owing to this circumstance, not only be impossible to adjust the longitudinal position of the centre of effort to any fixed trim of the ship which may have been found to be advantageous, but it will be equally impossible to determine the best longitudinal position for this point, after the ship is in a state of motion, since her trim will be subject to constant change.

Centre of effort below height of sail.

If the centre of effort, instead of being supposed to be situated above the true height of sail, be considered to be below that point, the immersion will take place at the after-extremity of the ship, from the action of the excess of the moment of the resistance of the water. It must also be observed, that there will be this difference in the two cases. When the centre of effort is above the height of sail, at every increase in the force of the wind the ship will, from the increased immersion of the bows, fly up to the wind, while the effect of the immersion of the after-part will be to make her fall off from it. The ill effects which have been described as attendant on the mal-position of the centre of effort of the sails with respect to the height of sail, though they cannot be removed while the cause exists, and which may consist in the improper proportions of the masts and yards, can in some cases be diminished by an alteration in the disposition of the weights on board the ship. If, instead of supposing the ship to incline, from the action of the force of the wind at the point E, we suppose the effort of this force to produce the inclination to be counteracted by the removal of a weight ($b$) from a point N at the fore-part of the ship, to another point O at the after-part, then the ship will be maintained in a state of equilibrium by the action of the two equal forces $a \cdot EF$ and $b \cdot NO$; and she will therefore move without longitudinal inclination, as long as the force of the wind remains constant; but any alteration in that force must be counteracted by a corresponding alteration in the position of the weight: also, when, from the action of the water on the hull, the ship acquires an angular velocity, the angular momentum will be increased by that of these two forces, which may both be considered as weights acting at their respective distances from the centre of gravity of the ship. It is therefore evident, that an error in the position of the centre of effort of the sails cannot be advantageously remedied by any alteration in the disposition of the weights in the ship, except in peculiar cases of smooth water; and further, if the error be that the centre of effort is above the height of sail, the ship will labour under the disadvantage of a diminished area of sail, since the moment of sail must be in constant proportion to the moment of stability; and if the centre of effort is too low, the ship may not be able to obtain all the advantage of motive power that her stability would admit of her applying.

Disadvantages of mal-position of centre of effort.

Centre of effort at true height of sail.

It appears, therefore, that unless the centre of effort of the sail be placed at the height of sail, a ship, however good her form, and the properties connected with it, may be, and whatever may be the care bestowed to render those properties most efficient, will labour under very serious disadvantages; while, on the contrary, a correct adjustment of this element, and a knowledge of the principles on which that adjustment depends, will place it in the power of a commander to obtain a maximum of advantage from the powers and properties of his vessel, since it will enable him to acquire the greatest possible efficient action from the motive power at his disposal.

As was before said, the determination of the height of sail must be classed among those problems of naval archi-

Difficulties attendant on the practical application of foregoing principles may be overcome.

tecture which, labouring under the difficulties attendant on our imperfect knowledge of fluids, cannot be attained by theory alone. It will now be shown that, by the aid of theory, sufficient deductions may be made from experiment to remedy its practical insufficiency. Throughout the foregoing considerations, the sails have been reasoned on as if they were plane surfaces. If this were the case, their centre of effort would coincide with their common centre of gravity; but, from the flexibility of the materials of which they are made, the sails become, when acted upon by the force of the wind, curved surfaces. However, from the whole surface of sail with respect to height being composed of several such surfaces, the error arising in practice from assuming the height of the common centre of gravity of the whole surface to be the height of the centre of effort, will be very inconsiderable; therefore, in practice the centre of effort of the sails may be represented, with respect to height, by their common centre of gravity.

Since we know, from the principles which have been explained, that when the centre of effort of the sails is at the true height of sail, the trim of the ship will not be subjected to alteration by any increase or diminution in the force of the wind, the height of sail for any trim may be determined by experiment, by first bringing the ship to that trim when she is at rest, and then adjusting the sails so that her water-line when in motion may be parallel to this trim. This being admitted, it is evident that, by proceeding on the principles already explained in this article, the maximum of advantage arising from the correct position of the centre of effort of the sail may be insured, by first ascertaining, from experiment and observation made with reference to the longitudinal position of the centre of effort with respect to the centre of gravity of the ship, the most advantageous draught of water, and then determining the correct height of sail with respect to that draught of water.

The observations necessary to effect these objects will require considerable patience and attention; but it must be considered that they will not only enable a commander to derive the greatest possible advantage from the means at his disposal, but that they will afford correct data for perfecting those means. The following observations may suffice to explain the principle which should be pursued. The draught of water previous to sailing should be observed; and an instrument which will correctly measure the angle of inclination should be fixed, in reference to this water-line, so that by means of it every deviation from this trim may be exactly known. This is rendered absolutely necessary, because, when a ship is in motion, her correct trim, that is, her horizontal water-line, cannot be observed, in consequence of the accumulation and depression of the water which is caused by the motion. In fact, any alteration made in the trim of the ship or the sails, founded on observations made with reference to the apparent water-line, might be extremely hazardous, and certainly would not produce the results expected, as the position of this water-line depends wholly on the circumstances which are in immediate operation. Having the instrument fixed, when the ship has acquired a uniform velocity observe the alteration which has taken place in her trim, as, until the velocity is uniform, the trim will be influenced by the force which accelerates the velocity. Then, if her longitudinal oscillations or her pitching motions appear to be only influenced by the state of the sea, the centre of effort is correctly placed at the height of sail. Therefore the height of the centre of gravity of the surface of sail set, will give the height of sail. But if at every change in the force of the wind the vessel experiences a sudden increase of longitudinal oscillation, observe by the instrument its nature and degree, and make such a change in the adjustment of the sails as the foregoing principles have shown to be necessary; and when the tendency to increased longitudinal oscillation ceases, find the height of sail by calculating the height of the centre of gravity of the surface of sail then set. In this manner the correct height of sail for any trim may be found; while, by observing at the same time the comparative qualities of the ship when at each of these trims (after the height of sail is determined for it), that trim of the ship and sails may be determined at which a maximum of advantage may be derived from the inherent good qualities of the ship, as far as the perfection of the *matériel* will admit, that is, as far as the position and proportion of the masts, yards, and sails, are adapted to the elements of the construction of the ship's body; while from knowing the best trim of the ship, and the true position of the centre of effort under the several circumstances of wind and sea, the naval architect will be in possession of sufficient data to make such alterations in the *matériel* as shall then insure a maximum of advantage with a maximum of the means. In fact, correct observations of this nature would go very far to remove much of the difficulty which theory, in its application to some points in the practice of naval architecture, at present labours under.

Recapitulation of principles.

The laws which govern the mutual action of the wind and water on a ship when she is in motion have now been explained, principally as they affect her equilibrium round a vertical or a horizontal axis of rotation; because by pointing out the various states of equilibrium which result between the action of the wind on the sails and the water on the hull, we are enabled to show the effects which may be produced on the qualities of the ship by modifications in these equilibrio; either by the use of the helm, by alterations in the trim of the ship, in the quantity of the sail set, or in the disposition of that quantity, so that in the various changes which may take place in the state of the wind or of the sea, the qualities of the vessel may either experience the least possible injurious effect, or the greatest possible degree of benefit, according as the tendency of the change may be injurious or beneficial. In pursuing this train of reasoning, we have also endeavoured to explain in what manner the principles that govern the mutual action of these forces may be made available in directing such observations on the performances of ships as may lead to the formation of correct conclusions on their powers and qualities, and guide us to the best means of rendering these qualities most easily available. It has also been shown, that by experiments and observations made according to the principles which have been advanced, a maximum of advantage may be obtained from a ship, as far as the form, the fitness of the proportions and positions of the masts and yards, the proportions of the sails, and the trim of the vessel, will admit; and, what is yet more important, that sufficient data may be obtained to enable the naval architect to judge correctly of the comparative perfection of those means, and so to form correct conclusions as to such deviations from them, as would either tend to their improvement or to obviate similar defects in a future design.

In every vessel a maximum of efficiency.

It is evident, that whatever may be the service required from a vessel, there must always be some maximum of efficiency with reference to those services, which is to be arrived at by a judicious combination of the powers of the vessel with the means which call them into action. The distinguishing division of the characteristics of the qualities required in vessels are mainly those peculiar to burden and those peculiar to velocity. In England, for the last century, we may say that burthen, to the sacrifice of every other quality, nay, even to an extent compromising the safety of the vessel and the lives of the crew, has been the solitary requirement in the design of a merchant-ship.

Distinct qualities, burthen and velocity.

In ships of war both necessary.

In ships of war, under almost all circumstances, it is a combination of the two which is the desideratum; and it is not sufficient that a vessel should be only capable of great velocity in direct courses, or when the propelling force acts in the direction of the keel; for it is in most cases of more

Theory.

importance that she should be capable of great velocity when acted upon by a force in a direction oblique to that of her length, and at the same time that the deviation of her course from this line should be the least possible.

Lee-way.

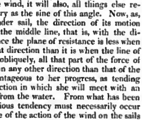
The principles on which this deviation of the course of a ship from the line of her keel, or the angle of lee-way, depends, will now be explained; and the causes will be shown which occasion the actual results of observations on ships to differ from the theoretic principles which have been advanced by writers on this subject; and such methods will be suggested for making further observations in reference to these qualities as may be desirable, with a view to collect data to supply the deficiencies resulting to the theory from the imperfect state of our knowledge respecting the resistances of fluids, particularly as they affect the oblique passage of a ship through the water.

Effective force of wind.

Whatever may be the angle which the direction of the wind makes with the plane of the sails, the only effective force of the wind on the sail is that part of the whole force which can be resolved into a direction perpendicular to the surface of the sails; therefore, whatever may be the whole force of the wind, its effective force will vary as the sine of the angle which the direction of the wind makes with the sail; and as the velocity of the ship is in proportion to the effective force of the wind, it will also, all things else remaining the same, vary as the sine of this angle. Now, as, when the ship is under sail, the direction of its motion should coincide with the middle line, that is, with the direction of the keel, since the plane of resistance is less when the ship moves in that direction than it is when the line of motion cuts the ship obliquely, all that part of the force of the wind which acts in any other direction than that of the keel must be disadvantageous to her progress, as tending to force her in a direction in which she will meet with an increased resistance from the water. From what has been said above, this injurious tendency must necessarily occur in every circumstance of the action of the wind on the sails of a ship, excepting in that under which the trim of the sails is at right angles to the middle line of the ship, as, under all circumstances, the force of the wind on the sail may be resolved into two, both of which will have effect on the ship, the one acting perpendicular and the other parallel to the middle line: or, if we suppose AB (fig. 9) to be the middle line of a ship, and CD the direction of the yard, making with AB the angle DEB less than a right angle; and suppose FE to represent the quantity and direction of the force of the wind; from E and F draw EG perpendicular and FG parallel to DC, and from G draw GH perpendicular to AB; then GE will represent the effective force of the wind on the sail, and GH and HE will be respectively equal to the parts of that force employed in propelling the vessel in a lateral and in a direct course. If CD, the direction of the yard, were perpendicular to AB the line of the keel, the lateral effort of the wind, or the force GH, would be lost, and have no effect on the ship; but when CD is oblique to AB, whatever may be the quantity or direction of the force FE of the wind with respect to AB, it may be resolved into two forces, both of which will be effective on the ship. As long as DEB, the angle formed by the direction of the yard with the line of the keel, remains the same, its complement, the angle GEH, will remain the same; and as GHE is a right angle, the triangle GEH will remain similar to itself, and the proportion between GH and HE will be invariable, and therefore the effort to cause the deviation of the course from the line of the keel, or the action of the force GH, will be in an invariable proportion to the force acting to propel the vessel along that line, or the force HE; and, as we know from what has been before said, that the forces GH and HE must be respectively equal to, and opposed by, the lateral and direct resistances of the water acting in the directions HG and EH, the motion of the ship must be along some line *ab*, such that the equilibrium between these forces may be maintained. This is the principle on which the deviation of the course of the ship from the line of the direction of the keel depends.

Investigation of the angle of lee-way.

Fig. 9.



Theory.

The angle of lee-way is determined as follows: Suppose the direct and lateral resistances of the water to the passage of the vessel to be respectively R and *r*, and the surfaces respectively opposed to these resistances to be *d* and *e*, and the angle DEB which the sail makes with the line of the keel to be *c*; then, if the angle of lee-way be supposed to be *x*, we have

$$R : r :: d \cdot \cos.^2 x : e \cdot \sin.^2 x$$

$$\therefore \frac{R}{r} = \frac{d \cdot \cos.^2 x}{e \cdot \sin.^2 x} = \frac{d}{e \cdot \tan.^2 x},$$

$$\text{and } \frac{R}{r} = \frac{EH}{HG} = \frac{\sin. c}{\cos. c} = \tan. c$$

$$\therefore \frac{d}{e \cdot \tan.^2 x} = \tan. c;$$

$$\text{or, } \tan.^2 x = \frac{d}{e} \text{cotan. } c$$

$$\tan. x = \sqrt{\frac{d}{e} \cot. c}.$$

From this equation, also, it appears that the angle of lee-way depends wholly on the angle of inclination of the sail to the line of the keel, without in any way involving the velocity of the ship; and most writers on naval architecture have in this manner considered the question of the equilibrium which exists between the force of the wind and of the resistance of the water in producing this angle. Bouguer has calculated an elaborate table of the angles of lee-way for various classes of ships for the several degrees of inclination of the sail to the keel, from 30° to 90°; but the results which he has obtained differ essentially from those derived from observation on the actual performances of vessels.

Bouguer.

According to the theory which has been explained, and on which Bouguer founded his calculations, the lee-way depends solely on the angle formed by the yard and the keel, and is uninfluenced by any other cause, and therefore is neither affected by the angle which the direction of the wind makes with the sail, nor by the velocity of the vessel; but this is contrary to the facts elicited by the experience of the actual motion of a ship under sail. From the geometrical construction which has been given, it is evident, that whatever may be the force or the direction of the wind, the proportion which GH bears to HE will increase as the angle DEB diminishes, and so far the theory agrees with experiment; but it is well known to all who have observed the motion of a vessel through the water, that without any alteration in the direction of the wind with the keel, the lee-way varies with every variation in the velocity of the vessel; and also, from this same cause, the alteration in the velocity, all things else remaining the same, if the angle formed by the direction of the wind with the keel be altered, the angle of the lee-way will also experience an alteration; in fact, so greatly does the angle of lee-way depend on the velocity of the ship, that in the same vessel, under similar circumstances of bracing of yards and direction of wind with the keel, the only varying circumstance being a difference in the force of the wind, the quantity of lee-way will vary from that which would occur by the ship's almost drifting in the direction of the sine of the angle of incidence of the direction of the wind on the sail, to that which would exist if her course almost coincided with the line of her keel, or to a quantity which, in practice, would evidently be scarcely observable.

Experiment at variance with theory;

but not an insurmountable objection.

There is some difficulty in accounting for this difference between the results of theory and the facts observed from experience. It depends in a great measure on the imperfection of our knowledge respecting the laws of the motion of bodies in fluids, so that we are unable to estimate the circumstances of the resistance of the water on the bows and on the sides of the ship. The results of the theory of resistances, when applied to oblique impulses, vary very considerably from the actual resistances as observed by experiment, more especially as the angles of incidence become more acute. This discrepancy affects the lateral resistance, or the resistance on the broad-side, more than the direct, or that experienced by the bows of the vessel, and therefore has a corresponding influence in causing the actual lee-way of a ship to differ from the theoretic result. But this, again, is one of those difficulties arising from the imperfect state of the theory of resistances, which may be classed among those which were referred to in the early part of these observations, as requiring "only to be fully known and understood, to be, if not absolutely theoretically solved, at least, from the collection of facts, from experiment, and from analogy, so far overcome, as to leave nothing to be desired." The course of these remarks will tend to show the possibility of this. Professor Robison, in the excellent article on Seamanship, speaking of the results deduced by Bouguer, says, "that the person who should direct the operations on ship-board in conformity to the maxims deducible from M. Bouguer's propositions, would be baffled in most of his attempts, and be in danger of losing his ship. The whole proceeds on the supposed truth of that theory which states the impulse of a fluid to be in the proportion of the square of the sine of the angle of incidence, and that its action on any small portion, such as a square foot of the sails or hull, is the same as if that portion were detached from the rest, and were exposed singly and alone to the wind and water in the same angle.... But let it be observed, that the theory is defective in one point only; and although this is a most important point, and the errors in it destroy the conclusions on the general propositions, the reasonings remain in full force, and the *modus operandi* such as is stated in the theory."

Another cause of deviation from theoretic conclusions.

There is another cause existing to occasion the deviation which is observable in the practical results of the lee-way of a ship from the conclusions of theory, which arises from the theory's not embracing the whole of the circumstances attendant on a vessel's motion through the water. By recurring to the explanation which has been given of these circumstances in a previous portion of this article, some further elucidation may be afforded to the unsatisfactory result of the theory. When motion is communicated to a vessel from a state of rest, or from a lesser degree of motion, the effort of the wind on the sails is greater than that of the water on the hull, whether to propel the vessel in the direction HE of the keel, or, laterally, in the direction GH, and the velocity of the vessel in each of these directions is accelerated by the excess of the force of the wind over the resistance of the water, until, ultimately, by the diminution in the relative velocity of the wind, and the increase of the relative velocity of the water, an equilibrium ensues between the propelling and the resisting forces, and the vessel continues to move in the direction of the last acting force, and with the last acquired velocity. Now the resistances of the water in the direction EH and HG may be assumed to increase as the squares of the velocities, and from the nature of the form of a vessel, and from the comparative direct and lateral resisting areas, the resistance arising from form or area is much smaller in a direct than in a lateral direction, and therefore the equilibrium between the forces which act laterally may ensue before that between the forces which act directly; in which case the lateral motion of the vessel will become uniform before the direct motion, and consequently the ultimate course or direction of the vessel, when all the forces have arrived at a state of equilibrium, will approximate to that of the last acting force, that is, will more nearly coincide with the direction of the keel, and the angle of lee-way will be diminished. As this reasoning depends on the intensity of the force of the wind, the effect will vary as the cause; and the greater the force of the wind, and consequently the velocity of the ship, the greater must be the diminution of the angle of lee-way, that is, the angle of lee-way will, so far as it is affected by these considerations, vary inversely as the sine of the angle of incidence of the wind on the sail.

Romme.

Romme, in his *Traité du Navire*, differs from the opinions advanced by Bouguer; and though his reasoning on this subject is far from clear, his opinions are valuable, as he founds the conclusions at which he arrives, that the lee-way varies inversely as the square of the velocity, and that it increases with the obliquity of the sails to the keel, principally on observations and experiments on the actual performances of vessels; and these are the only means by which, as yet, we can hope to arrive at the solution of this problem. However, much further observation is necessary to afford sufficient data on which to found an approximation to the lee-way which a vessel makes. The general facts which influence it appear to be the greater or lesser angle of incidence of the wind on the sail, as the velocity of the ship is dependent on this; the angle of the inclination of the sails with the keel; the form of the vessel as it affects the ratio of the direct and lateral resistances; the form of the vessel as it affects the velocity; the stability as it affects the lateral resistances; the quantity of sail set; and the state of the sea.

Tables might be formed.

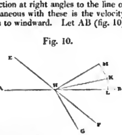
Experiments which may be made.

The distance which a ship falls to leeward of her course in any given time may generally be very easily ascertained; and it would not be a task of any great difficulty to form tables, from actual observation, for ships, under all the various circumstances which have been shown to affect the deviation of their course from the line of direction of the keel. In the open sea the quantity of lee-way made in any certain time may be easily ascertained by measuring the angle which the ship's wake makes with the line of the keel; then, if the distance run during the time for which the lee-way is to be observed be ascertained, as that distance is measured along the line of lee-way, the distance run in any period of time will be to the distance which the ship has fallen to leeward of her course during that time, as radius to the sine of the angle of lee-way. When a ship is in sight of land, the angle which the direction of the keel makes with the line of lee-way may be more correctly observed by means of a fixed object on the shore, whenever the state of the wind and sea may render an estimation of the lee-way desirable, that is, whenever the wind is sufficiently steady; as, of course, it is supposed that the angle formed by the direction of the wind with the line of the keel will remain constant during the whole time for which the distance fallen to leeward is to be ascertained. If, when the ship is either approaching or leaving the shore, her head be constantly kept to the same point of the compass, the ship's course will be along the line of lee-way; and as all things are supposed to remain constant during the time of the observation, this line will form a constant angle with the line of the keel, and therefore the point on the shore, which will have the same bearing from the ship as the line of lee-way, will remain at that bearing during the whole time in which the ship either approaches to or recedes from the shore. Consequently, if, when a ship either approaches to or recedes from a shore, an object on the shore be observed which has a constant bearing from the ship, it must be in the direction of the line of lee-way, and therefore the angle which it makes with the direction of the keel will be the correct angle of lee-way; and then, as before, if the distance run in any time be taken as the radius, the distance which the ship has fallen to leeward of her course in that time will be equal to the sine of the angle of lee-way to a radius equal to the distance run by the vessel in the time assumed.

The actual quantity gained to windward in any given time may also be easily ascertained. The motion of the vessel through the water may be considered in four directions, and the velocity with which it advances in either of these directions determined.

The actual velocity of the ship, or the velocity along the line of lee-way, which may be called the oblique velocity, may be resolved into two; the direct velocity, or that estimated in the direction of the keel, and the lateral velocity, or that which is in a direction at right angles to the line of the keel; and contemporaneous with these is the velocity with which the ship gains to windward. Let AB (fig. 10) be the direction of the line of the keel of the vessel, and EF the direction of the yard, cutting that direction of the keel obliquely. Then, whatever may be the direction of the wind GH, the course of the vessel will be along some line HK, forming an angle KHB with the direction of the keel; then suppose HK on the line of lee-way to represent the velocity of the ship in that direction, from K draw KL perpendicular to HB, and cutting HB in L; then the velocity HK is equal to the two velocities HL and LK; and HL and LK will represent respectively the direct and lateral velocities of the vessel, in proportion to the oblique velocity HK; and if from the points H and K, HM be drawn perpendicular and KM parallel to the direction of the wind GH, MK will represent the velocity with which the ship has gained to windward in the time in which she has described the space HK. For the origin of the wind being supposed to be at an infinite distance from the vessel, as HM is drawn perpendicular to GH, the direction of the wind, it may be supposed equidistant in every point from the origin of the wind; and as the angle GHK is less than the angle GHM, the line HK is within the line HM; and therefore the point K is nearer the origin of the wind than the point H, by a quantity equal to the perpendicular distance KM, of the point K, from the line HM; or the ship has gained the distance MK to windward in running from H to K. It is evident that if HM coincided with HK, the ship would neither have gained to windward nor fallen to leeward; and that if HM fell within HK, the ship would have fallen to leeward. When the distance HK run by the vessel along the line of lee-way, and the angle of lee-way KHL, are known, the value of KM may be easily determined; for since the angles GHF, FHL, and LHK, are all known, and the line MH is drawn perpendicular to HG, their complement, the angle MHK, is known; therefore, as HMK is a right angle, HK is to KM as radius is to the sine of the angle KHM; or KM is the sine of the angle KHM, to a radius equal to the distance run by the vessel in the space of time in which the required distance to windward, KM, was to be gained. The only difficulties in the practical solution of this proposition are, to determine the direction HM, or the perpendicular to HG, the direction of the wind, and the value of the angle GHF; for when the vessel is in motion, unless the directions of the wind and of the course of the vessel coincide, that is, unless the vessel is before the wind, the direction of the wind as shown by the vane on board will not be its true direction; for, from the velocity of the vessel through the air, the vane is subject to a force acting upon it in a direction opposed to that of the course of the vessel, the effect of which may be considered the same as if the vane was at rest, and was acted upon by a current of air having a velocity equal to that of the vessel, but acting in an opposite direction; consequently the vane is acted upon by two forces, the one in the real direction of the wind, acting with a velocity equal to the velocity of the wind in that direction, and the other acting in a direction opposed to that of the course of the vessel, with a velocity equal to that of the vessel in its course; and therefore the direction of the vane will be the diagonal of the parallelogram of which the sides represent these two forces in quantity and direction. It is therefore evident that, all things else remaining the same, the greater the velocity of the vessel, the more will the direction of the wind, as shown by the vane, or the apparent wind, deviate from the actual direction of the wind, or the true wind; and as this deviation arises from the action of a force in a direction opposed to the motion of the vessel, or acting along the line of the course from the fore-part of the vessel towards the after-part, the apparent direction of the wind will in all cases head the vessel more than the true direction of the wind, and consequently the vessel will always appear to lie nearer the wind than she actually does.

Fig. 10.



Vessels appear to lie nearer to the wind than they actually do lie.

True direction of the wind.

The true direction of the wind may be found if the velocity and direction of the vessel be known, and also the velocity and direction of the apparent wind, as the corresponding velocity and direction of the true wind will form the third side of a triangle, of which the three sides will be to each other as the three velocities; and as two of these are known, and include a known angle, that formed by the direction of the apparent wind with the course of the vessel, the third side, or the direction and velocity of the true wind, may be easily found. But as there is a difficulty in ascertaining the velocity of the apparent wind, the most easy way of determining the direction of the true wind will be by observing the arc through which the ship's head passes from close-hauled on one tack to close-hauled on the opposite tack. The bisection of this arc will, all things else remaining the same, give the direction of the true wind, as the course of the vessel, in relation to the direction of the wind, will be the same on either tack. Or the directions of the apparent wind may be observed both before and after tacking, and the true wind will be the middle point between the two directions, as the cause of the deviation of the direction of the vane from that of the true wind, or the velocity of the vessel, will be equal on each tack; and when the direction of the true wind is known, all the other parts of the triangle may be found, as the direction and velocity of the ship are known, and also the angle made by the apparent wind with that direction.

Should the velocity of the vessel be greater on one tack than on the other, it will be necessary, in order to determine the direction of the true wind, to divide the arc described by the vane when the ship is tacked into two segments, which shall be to each other in the inverse ratio of the velocities of the vessel on the tacks adjacent to these segments.

Nearest approximation of course to the wind.

Writers on naval architecture and seamanship appear to have fixed the limit of the angle which is formed by the direction of the wind with the line of the keel, when a ship is close-hauled, at six points. This exceeds the angle which the writer of this article has repeatedly observed, by the means which have been described, as being formed by the direction of the wind with the line of the keel, on board the Acorn, one of the corvettes of the experimental squadron of the year 1827. The following table will show the results of some of the observations then made.

Theory.

| Ship's Head before Tacking. | Ship's Head after Tacking. | No. of Points difference. | State of the Wind. |
|---|---|---|---|
| S. S. E. ½ E. | W. ½ N. | 11 | Fresh breeze. |
| W. by S. ½ S. | S. S. E. ½ E. | 9 | Light airs. |
| S. S. E. ½ E. | W. by S. ½ S. | 9 | Light airs. |
| W. ½ N. | N. by E. ¾ E. | 9½ | Moderate. |
| N. W. by N. | E. by N. | 10 | Fresh breeze. |
| S. S. E. | W. | 10 | Very fresh. |
| W ½ S. | S. E. by S. | 10½ | Very fresh. |

The second and third observations in this table were made on the same day. Their correctness receives farther confirmation from the circumstance, that when the Acorn was on the larboard tack, with her head W. by S. ½ S., the Columbine, another corvette of the squadron, was on the Acorn's beam, and it was ascertained from an observer on board the Columbine, she was lying about SE. by S. on the starboard tack; she must therefore have been lying as near the wind as the Acorn. The wind was very light, the rate by log being only one knot two fathoms; the angle of leeway, as observed by the wake, was seven degrees. It is desirable that similar observations should be made for all classes of ships; the circumstances of sea, wind, and rate by log, should also be noticed, that when any comparison is instituted, a due allowance may be made for their influence.

Limit to the velocity of a ship.

We have seen that the velocity of the ship depends on the strength of the wind. Writers on naval architecture have advanced various opinions as to the practicable limit to the velocity of a ship, in comparison with that of the wind. Bouguer endeavours to prove that the velocity of a fast-sailing ship is, when going nearly before the wind, about $\frac{3}{7}$ths of the velocity of the wind, and that merchant-ships seldom attain to more than one fifth of its velocity; but he considers it not impossible that fast-sailing frigates may arrive at a velocity about equal to half that of the wind. Don Juan objects to Bouguer's limit, as too restricted; he corroborates the opinions he advances by the results which he has deduced from experiment and observation on the actual performances of ships. He says that fast-sailing vessels acquire a velocity nearly equal to that of the wind, even when going before the wind. The nearest approximation to this velocity which he observed was as twenty-one to twenty-three; the average conclusion at which he arrives is, that when the course of the ship and the direction of the wind nearly coincide, the velocity of the ship is from $\frac{2}{3}$ds to $\frac{19}{27}$ths of that of the wind.

May exceed that of the wind.

But in oblique courses it is very possible for the vessel to acquire a velocity even greater than that of the wind, if we admit the conclusions of Don Juan to be correct. The reason of this will appear evident on a very slight consideration. The velocity with which the wind acts on the sails after the ship has acquired motion is only its relative velocity, that is, the excess of its actual velocity above the velocity which the ship has acquired in the direction of the wind. Now, when the directions of the wind and of the course of the vessel coincide, this relative velocity of the wind is only the difference between the actual velocities of the wind and of the vessel; but when the course of the vessel is oblique to that of the wind, the relative velocity of the wind is the difference between the actual velocity of the wind and that part of the velocity of the vessel which can be resolved in the direction of the wind. Robison, in the article on Seamanship, says, that when the sails are square to the keel, and the wind right aft, the ship's velocity is in direct proportion to the relative velocity, and to the square root of the surface of the sails; therefore, he says, " in order to increase the relative velocity by an increase of sail only, we must make this increase of sail in the duplicate proportion of the increase of velocity."

When the sails are oblique to the keel, he says " the velocity of the ship is proportional to $\sqrt{S \cdot V} \cdot \sin. a$; that

is, directly as the velocity
of the absolute inclination
rectly as the square root of
agrees with the conclusions
and it is evident that, the
the same, and the sine of
wind to the yard becoming
whole force of the wind act
the yard, the velocity of th
of the sails set, and may the
ing, be increased without li

From all the conclusion
the course of these remark
wind and water on a ship, i
gree of perfection in the
with reference to her motio
to her course through the
the suitableness of the disp
to the form of the vessel.
between these elements is e
son alike show, that the mo
ed to the qualities of her f
formances approach to pe
the proportions and form o
ing near the wind, and of
cannot evidently be made
form to their full extent, u
for rendering such quali
which the form and propo
ing in oblique courses, by
for such forms and courses
the degree of advantage i
would otherwise be capabl
time fall far short of the
capable in direct courses.
sail well, her form must
and quickness of manœuv
to her form; and she must
petent to develope the adv

The first of the followi
work, Scales of Displacem
ber of the late School of N
was formed by Mr Henwo
establishment, and publish
United Service Journal.
the master shipwright of H
ham, and published in the

These tables compose
some of the elements of
and, within their limits, ca
naval architect; because,
chitecture is a science of con,
and analogies. To the reader of the foregoing pages of this article it need scarcely be observed, that there yet remain many difficulties opposed to its being perfected, and that these can only be removed by a rigorous course of inductive investigation applied to the results of a patient, an attentive, and, above all, a competent comparison of the reported qualities and performances of ships, with an analysis of the elements of their design. When the School of Naval Architecture shall be re-established, as it most assuredly will be, the exercises of the students in their calculations, and their experiments on ships, may be made available to this end, by gradually obtaining the preliminary analysis of the whole navy of England; a work of very far too great labour for any thing but the combined endeavours of many individuals to accomplish; and when accomplished, of too vast extent, and of too varied and too conflicting results, to be grappled with by any but by a mind apt to conceive, to collate, and to generalize, and competent to submit these generalizations to the ordeal of strict mathematical investigation.

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TABLE I.—*Of the principal Dimensions of the several Classes of Ships composing the British Navy, and of several of their principal Elements.*

| | | | | | | | | | | | | | | | | Cutters. | | Steam Vessels. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of guns | | 120 | 84 | 76 | 74 | Razée. | 74 | Razée. | 60 | 46 | 42 | 28 | Fir. 28 | 18 | 10 | 10 | | | | |
| Burthen in tons | | 2808 | 2270 | 1025 | 1741 | 1741 | 1614 | 1814 | 1474 | 1073 | 943 | 499 | 499 | 429 | 382 | 235 | 160 | 108 | 296 | 237 |
| | | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. |
| Length of the gun-deck of ships of the line, and flush-decked vessels; and lower deck of frigates | | 205 5½ | 100 5½ | 182 0 | 170 0 | 170 0 | 168 0 | 168 0 | 172 9 | 151 8 | 145 0 | 113 8 | 113 0 | 109 6 | 100 0 | 90 0 | 70 8½ | 60 9 | 126 0 | 115 0 |
| Length on the keel, for tonnage | | 170 11 | 101 11½ | 150 0¾ | 145 1 | 145 1 | 137 10½ | 137 10½ | 144 9 | 125 0 | 121 8¾ | 04 8¾ | 04 8¾ | 86 9½ | 77 3½ | 75 7 | 52 3¼ | 49 5 | 111 0¾ | 101 2½ |
| Breadth, extreme | | 54 8 | 51 5½ | 40 0 | 47 6 | 47 0 | 46 11 | 40 11 | 43 0 | 39 11 | 38 2 | 31 0 | 31 6 | 30 6 | 30 5 | 24 6 | 24 0 | 20 4 | 22 4 | 21 0 |
| Breadth, moulded | | 53 0 | 50 8½ | 48 4 | 40 10 | 46 10 | 46 3 | 46 3 | 43 0 | 39 3 | 37 5 | 31 0 | 31 0 | 30 0 | 30 0 | 24 0 | 23 7 | 10 11 | 21 10 | 20 7 |
| Depth in the hold | | 23 2 | 22 6 | 20 6 | 21 0 | 14 0 | 10 9 | 13 3 | 14 5 | 12 8 | 13 3 | 8 0 | 8 0 | 12 9 | 12 0 | 11 0 | 11 0½ | 8 0 | 13 6 | 11 0 |
| Main wale, thickness used in the calculations | | 0 10 | 0 0 | 0 8½ | 0 8½ | 0 8½ | 0 0½ | 0 8½ | 0 7½ | 0 5 | 0 6 | 0 5 | 0 5 | 0 4½ | 0 4½ | 0 4 | 0 3½ | 0 3½ | 0 5 | 0 4 |
| Plank of the bottom | | 0 5 | 0 4½ | 0 4 | 0 4 | 0 4 | 0 4 | 0 4 | 0 4 | 0 4 | 0 4 | 0 3 | 0 3 | 0 3 | 0 3 | 0 3 | 0 2½ | 0 2½ | 0 3 | 0 2½ |
| Depth from the lower edge of the rabbet in the keel, to the lower side of the false keel | | 2 3 | 1 7 | 1 9 | 1 0 | 1 8 | 1 0 | 1 8 | 1 8 | 1 3½ | 1 3½ | 1 4 | 1 4 | ... | ... | 1 0 | 1 3½ | 0 11½ | 0 8 | 0 7 |
| Midship port above the water | | 5 8 | 5 6 | 5 5 | 5 8 | 0 8 | 5 4 | 7 4 | 8 0 | 6 0 | 7 0 | 4 0 | 4 8 | 4 0 | 4 6 | 4 2 | 4 1½ | 3 6 | ... | ... |
| Draught of water when loaded, or with the above height of midship port from the water | forward | 24 0 | 22 0 | 21 4 | 21 6 | 18 10 | 20 5 | 10 6 | 20 6 | 18 0 | 17 5 | 14 8 | 14 6 | 10 0 | 10 0 | 10 10 | 8 0 | 7 0 | 9 8½ | 7 2 |
| | abaft | 25 1 | 25 8 | 23 4 | 23 5 | 20 2 | 22 8 | 20 5 | 20 0 | 18 4 | 18 8 | 15 6 | 15 6 | 13 2 | 13 2 | 12 5 | 13 6 | 11 0 | 8 0½ | 7 2 |
| Draught of water when launched | forward | 15 1 | 13 2 | 14 2 | 13 0 | 12 0 | 12 2 | 11 0 | 12 2 | 10 0 | 10 8 | 0 5 | 5 0 | 5 0 | 5 0 | 7 3 | 8 4 | 5 0 | 5 1 | 4 9 |
| | abaft | 18 4 | 10 0 | 17 11 | 17 0 | 10 2 | 17 7 | 16 0 | 15 2 | 14 8 | 14 1 | 12 5 | 11 0 | 8 0 | 8 0 | 0 5 | 9 8 | 9 0 | 6 5 | 5 2 |
| Displacement when loaded, measured to the mean draught of water in each body | fore-body, in tons | 2400 | 1960 | 1570 | 1552 | 1268 | 1352 | 1152 | 1128 | 852 | 764 | 403 | 344 | 257 | 228 | 140 | 83 | 55 | 218 | 128 |
| | after do. | 2320 | 1880 | 1526 | 1470 | 1136 | 1272 | 1064 | 1012 | 740 | 696 | 365 | 324 | 240 | 216 | 142 | 93 | 54 | 190 | 103 |
| Sum of the displacements of the two bodies | | 4720 | 3840 | 3102 | 3028 | 2404 | 2624 | 2210 | 2140 | 1592 | 1460 | 768 | 668 | 506 | 444 | 291 | 176 | 109 | 408 | 231 |
| Difference of the displacement of the two bodies | | 80 | 80 | 50 | 70 | 132 | 80 | 88 | 110 | 112 | 68 | 38 | 20 | 5 | 12 | 7 | 10 | 1 | 28 | 25 |
| Displacement when launched | fore-body, in tons | 1280 | 1024 | 960 | 880 | 780 | 760 | 675 | 568 | 436 | 408 | 225 | 144 | 136 | 108 | 78 | 53 | 41 | 57 | 68 |
| | after-body, do. | 1120 | 824 | 824 | 720 | 640 | 624 | 544 | 472 | 324 | 320 | 180 | 120 | 96 | 70 | 57 | 31 | 22 | 68 | 52 |
| Sum, or weight of the hull | | 2400 | 1848 | 1784 | 1600 | 1420 | 1384 | 1220 | 1040 | 760 | 728 | 405 | 264 | 232 | 178 | 135 | 84 | 63 | 155 | 120 |
| Difference between the load and the launching displacements, or the absolute burthen, in tons | | 2320 | 1992 | 1318 | 1428 | 084 | 1240 | 095 | 1100 | 832 | 732 | 363 | 404 | 274 | 266 | 156 | 92 | 46 | 253 | 111 |

TABLE I.—*Continued.*

| Number of guns | 120 | 84 | 78 | 74 | Razée. | 74 | Razée. | 60 | 48 | 42 | 28 | Fir. 28 | 18 | 18 | 10 | Cutters. |  | Steam Vessels. |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. | Ft. In. |
| Length of the vessel at the load water-line, that is, between the fore side of the rabbet of the stern and the aft side of the rabbet of the stern-post | 205 3 | 195 9 | 182 0 | 178 0 | 175 4 | 168 3 | 168 0 | 173 0 | 153 0 | 145 3 | 115 0 | 115 0 | 106 9 | 97 3 | 87 2 | 66 0 | 57 0 | 120 5 | 108 4 |
| Extreme breadth at the load water-line | 55 6 | 52 2½ | 49 9 | 48 3 | 47 9 | 47 8 | 47 8 | 44 3 | 40 3 | 38 6 | 31 10 | 31 10 | 30 3 | 30 3 | 24 6 | 23 8 | 20 0 | 22 8 | 21 3 |
| Mean difference between the load and launching draughts of water | 8 8 | 6 8 | 6 3 | 7 1½ | 5 2 | 0 7½ | 5 8 | 6 4 | 8 2 | 8 10½ | 4 0½ | 4 3½ | 4 1 | 4 8½ | 3 3½ | 3 1½ | 2 0 | 4 0½ | 2 2½ |
| Distance of the centre of gravity of the displacement below the load water-line | 10 0 | 6 $10\frac{5}{16}$ | 6 2½ | 8 $1\frac{6}{16}$ | 0 0 | 7 $7\frac{6}{16}$ | 8 $10\frac{6}{16}$ | 8 $0\frac{6}{16}$ | 0 9 | 0 6 | 4 $10\frac{5}{16}$ | 4 6½ | 4 $1\frac{3}{16}$ | 4 0 | 3 6 | 3 0 | 2 0½ | 3 $3\frac{5}{16}$ | 2 5½ |
| Distance of the centre of gravity of the displacement before the middle of the length of the load water-line | 2 0 | 1 $4\frac{3}{16}$ | 1 9 | 2 0 | 2 0 | 2 $1\frac{5}{16}$ | 2 0 | 2 2 | 3 3½ | 1 11½ | 1 $7\frac{5}{16}$ | 1 $7\frac{3}{16}$ | 0 $7\frac{5}{16}$ | 0 6 | 0 5½ | 8 0 | 0 $8\frac{4}{16}$ | 3 $2\frac{5}{16}$ | 2 9 |
| Distance of the principal transverse vertical section before the middle of the length on the load water-line | .18 0 | 13 6 | 8 0 | 20 0 | 14 4 | 15 8 | 13 3 | 8 0 | 10 0 | 15 0 | 15 0 | 15 0 | 13 0 | 8 6 | 8 0 | 2 0 | 5 6 | 10 8 | 8 0 |
| The same distance in proportion to the length of the load water-line | ·088 | ·869 | ·041 | ·11 | ·081 | ·092 | ·06 | ·049 | ·065 | ·10 | ·13 | ·13 | ·12 | ·087 | ·091 | ·03 | ·096 | ·087 | ·079 |
| Area of the principal transverse vertical section, in square feet | 1056 | 988 | 810 | 802 | 658 | 740 | 646 | 618 | 540 | 500 | 320 | 280 | 241 | 241 | 164 | 136 | 102 | 166 | 104·8 |
| Area of the load water-section, in square feet | 10012 | 8960 | 7952 | 7608 | 7176 | 6016 | 6672 | 6704 | 5260 | 4776 | 3264 | 3160 | 2632 | 2368 | 1796 | 1232 | 946 | 2400 | 1894 |
| Displacement per inch at the load water-section, in tons | 23·83 | 21·33 | 18·9 | 18·1 | 17·09 | 16·40 | 15·9 | 15·96 | 12·82 | 11·37 | 7·77 | 7·52 | 8·27 | 5·63 | 4·28 | 2·9 | 2·26 | 5·7 | 4·5 |
| Area of the launching water-section, in square feet | 8440 | 7176 | 6760 | 6280 | 6040 | 5812 | 5570 | 5336 | 4006 | 3760 | 2808 | 2288 | 2160 | 1680 | 1360 | 880 | 740 | 1808 | 1610 |
| Displacement per inch at the launching water-section, in tons | 20·0 | 17·1 | 16·1 | 14·95 | 14·4 | 13·83 | 13·26 | 12·7 | 9·54 | 8·95 | 6·68 | 5·45 | 5·0 | 4·0 | 3·24 | 2·09 | 1·76 | 4·49 | 3·83 |
| Area of the sails, viz. jib, driver, courses, topsails, and top-gallant sails, in square feet | 25619 | 26724 | 24228 | 23027 | 24374 | 23027 | 24374 | 23027 | 16651 | 16107 | 10152 | 10152 | 9605 | 9277 | 6246 | 4825 | 3502 | ... | ... |

NOTE.—The depth of the lower side of the false keel, below the lower edge of the rabbet, for the brigs of eighteen guns, is not inserted in the table, as an additional false keel is put to these vessels when they are altered from brigs to ships, giving them an increase of six inches of false keel forward, and no increase aft. On this account the draught of water given for them in the table is measured from the upper side of the main keel.

TABLE II.

| | Length of Load Water-line. | | Breadth, extreme, at ditto. | | Depth from ditto to lower edge of Keel Rabbet. | Draught of Water. | | | | Displacement, in Tons. | Centre of Gravity of ditto before the middle of Load Water-line. | Displacement before Centre of Gravity. | Displacement abaft Centre of Gravity. | Difference of Fore and After Bodies. | Distance of Centre of Gravity of Fore-body from Centre of Gravity of the Displacement. | Distance of ditto of After-body from ditto. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Forward. | | Aft. | | | | | | | | |
| | Feet. | In. | Feet. | In. | Feet. | Feet. | In. | Feet. | In. | Tons. | Feet. | Cub. Ft. | Cub. Ft. | Cub. Ft. | Feet. | Feet. |
| Rodney, 82 guns............ | 204 | 0 | 54 | 4¾ | 21·27 | 23 | 0 | 24 | 1½ | 4165¾ | 2·445 | 73550 | 72250 | 37·14 | 40·99 | 41·72 |
| Queen, 110 guns............ | 202 | 5 | 59 | 8½ | 22·91 | 22 | 5½ | 23 | 5½ | 4482¾ | 1·843 | 79320 | 77574 | 49·9 | 40·51 | 41·42 |
| Vengeance, 84 guns......... | 194 | 2 | 52 | 2½ | 20·655 | 21 | 7½ | 23 | 1½ | 3387 | 3·672 | 59056 | 58702 | 33·0 | 37·09 | 37·82 |
| *Vengeance, 84 guns........ | 194 | 11½ | 52 | 2½ | 21·825 | 22 | 1 | 24 | 10 | 3680 | 2·467 | 64836 | 63974 | 24.1 | 37·74 | 38·25 |
| Winchester, 52 guns........ | 172 | 7 | 44 | 3 | 19·1 | 20 | 1 | 21 | 2 | 2279 | 1·662 | 40180 | 39602 | 18·5 | 33·54 | 34·03 |
| *President, 52 guns......... | 172 | 10 | 44 | 11 | 18·5 | 19 | 1 | 21 | 8 | 2123½ | 4·397 | 38059 | 36262 | 51·4 | 32·95 | 34·50 |
| Seringapatam, 46 guns...... | 159 | 4 | 41 | 0 | 16·05 | 18 | 8½ | 18 | 2½ | 1531 | 2·84 | 27226 | 26366 | 24·6 | 31·56 | 32·58 |
| Inconstant, 36 guns........ | 160 | 0 | 45 | 0 | 10·00 | 18 | 5 | 19 | 5 | 1862 | 2·79 | 32975 | 32182 | 22·4 | 30·74 | 31·49 |
| Minerva, 46 guns........... | 152 | 9 | 40 | 1½ | 18·32 | 17 | 8 | 18 | 8 | 1420 | 2·30 | 26381 | 23948 | 69·4 | 25·103 | 27·688 |
| Sapphire, 20 guns.......... | 120 | 0 | 34 | 0 | 13·42 | 14 | 1½ | 15 | 5½ | 770 | 1·70 | 13636 | 13330 | 0·8 | 23·22 | 23·75 |
| Imogene, 28 guns........... | 128 | 0 | 33 | 10 | 14·42 | 15 | 6 | 16 | 4 | 073 | 2·17 | 15517 | 15052 | 13·2 | 24·78 | 25·54 |
| Challenger, 28 guns........ | 128 | 11 | 32 | 8½ | 15·1 | 18 | 7 | 16 | 7 | 943 | 2·35 | 16730 | 18288 | 12·8 | 24·76 | 25·43 |
| Rover, 18 guns............. | 109 | 8 | 34 | 0 | 13·05 | 13 | 11½ | 14 | 11½ | 563 | 2·253 | 10017 | 9722 | 8·4 | 20·74 | 21·37 |
| Orestes, 18 guns........... | 111 | 2 | 31 | 0 | 12·87 | 13 | 10 | 14 | 7 | 606 | 2·485 | 10805 | 10403 | 11·5 | 21·63 | 22·46 |
| Champion, 18 guns.......... | 110 | 10 | 31 | 1 | 12·92 | 14 | 6 | 14 | 8 | 615·8 | 1·226 | 10824 | 10732 | 2·66 | 21·94 | 22·12 |
| Columbine, 18 guns......... | 102 | 7 | 33 | 2½ | 13·4 | 14 | 4½ | 14 | 10¾ | 524·8 | 4·25 | 9435 | 8933 | 14·3 | 18·79 | 19·84 |
| Scylla, 18 guns............ | 97 | 6 | 30 | 0 | 11·33 | 10 | 7 | 14 | 3 | 421·8 | 1·312 | 7526 | 7239 | 8·2 | 17·81 | 10·88 |
| *Waterwitch, 10 guns....... | 88 | 11 | 28 | 8½ | 11·142 | 10 | 2 | 14 | 6 | 330·8 | ·167 | 5804 | 5774 | ·56 | 16·44 | 18·52 |
| Britomart, 10 guns......... | 86 | 9 | 24 | 7 | 9·81 | 10 | 7¾ | 12 | 3¾ | 278·0 | ·517 | 4920 | 4808 | 3·5 | 16·66 | 17·05 |

* The calculations for the ships thus marked are made to the sea-going draughts of water; for the others, to the draughts of water on the drawings.

TABLE III.—*Moments of Sail, of Stability, and of Sail in terms of the Stability, in Ships which have carried their Sail well.*

| Three-decked Ships. | | | Two-decked Ships. | | | Frigates. | | | Sloops. | | | Brigs of 18 Guns. | | | Brigs of 10 Guns. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moments | | | Moments | | | Moments | | | Moments | | | Moments | | | Moments | | |
| of Sail. | of Stability at 10° Inclination. | of Sail in terms of Stability. | of Sail. | of Stability at 10° Inclination. | of Sail in terms of Stability. | of Sail. | of Stability at 10° Inclination. | of Sail in terms of Stability. | of Sail. | of Stability at 10° Inclination. | of Sail in terms of Stability. | of Sail. | of Stability at 10° Inclination. | of Sail in terms of Stability. | of Sail. | of Stability at 10° Inclination. | of Sail in terms of Stability. |
| | Tons. | | | Tons. | | | Tons. | | | Tons. | | | Tons. | | | Tons. | |
| 2,632,121 | 3452 | 762 | 1,750,165 | 2280 | 767 | 1,276,577 | 1647 | 775 | 554,484 | 547 | 1013 | 442,413 | 409 | 1081 | 247,645 | 207 | 1196 |

## *Description of several Mechanical Methods of Designing the Body of a Ship.*

Mechanical processes substituted for correct principles.

The following mechanical methods of designing the forms of midship sections, and of ships' bodies, have been published in different English and French works on naval architecture. Some of these are for forming the midship section alone; others are for deducing the successive sections forward and abaft from a given midship section. Such methods of endeavouring to compensate for the absence of more correct principles on which to found the design of a ship, were rendered necessary whenever the vessel to be built was of too large a size to admit of being conveniently put up by the aid of the eye alone; and consequently almost every merchant-builder is in possession of some such empirical system, to enable him to form a design for a ship. Whether the ship built after the design so formed, will prove to be possessed of good or of bad qualities, does not generally enter into the consideration, excepting in so far as the crude ideas of the inventor of the system may have guided him in forming it. We say the crude ideas, because the builder whose judgment is sound enough to enable him to arrange facts and classify observations, and whose experience has been extensive enough to have furnished him sufficient facts from which to deduce principles, will abandon all such attempts as futile, and will pursue the study of naval architecture in the manner in which alone it can be studied to certain advantage, that is, as an inductive science. His success will depend on his fitness for the task.

If all the principles which are involved in the design for a perfect ship were developed, and correct results could be obtained by calculation on every point involved, a system might be formed. A system might also be formed combining all the present knowledge on the subject; but this is far from desirable; it would necessarily be imperfect, and it would be entailing imperfection on the future.

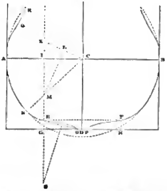
Methods for forming midship sections.

M. Bouguer, in his *Traité du Navire*, gives four methods which have been used for describing the midship sections of ships. He observes, that in these plans the midship sections are generally formed of arcs of circles; but that sometimes, through the ignorance of the inventors, of the fact, that for two arcs of circles to touch each other without cutting, their centres must be in the straight line which passes through their point of contact, the midship sections which they formed by these arcs had not even the advantage of being curves, but had angles in their contour. He shows how this error may be avoided. The first method he gives

By the Père Fournier.

is that of Le Père Fournier. A straight line AB (fig. 11) is drawn, which he takes to represent the moulded breadth of the ship. A circle RANB, which has this line for the diameter, is then described; and, bisecting AB in C, he draws the perpendicular CD, equal to the depth intended to be given to the vessel, which extends from the under part of the beam to the upper side of the keel. Through the point D he draws a line parallel to AB, and, making DG and DH each equal to half the flat of the floor, equal also, if so determined, to one fourth of the whole breadth, he draws the verticals GE and HF equal to the rising of the floor. These may be assumed equal to the twenty-fourth, the eighteenth, or the twelfth part of GH. He then finds on GE, produced both ways to K and S, a point M, which he takes for the centre of an arc of a circle NE, that touches the first circle in some point N, and the straight line EF in E. Then with a point S assumed as a centre he describes the arc EO, which, touching the straight line EF or the arc NE in E, meets the side of the keel in O. He has thus ANEO for the form of half the section, and the other side is drawn in the same manner.

Fig. 11.



Bouguer's correction.

Bouguer corrects this method thus: He takes EK equal to the radius CA of the first circle, or equal to half the length of the beam, and having joined the points K and C by the straight line CK, if it be bisected in L, and LM be drawn perpendicular to it, the intersection of this perpendicular with EK will be the centre M of the arc NE. For MC being equal to MK, and EK having been made equal to AC or to NC, it is evident that MN will be equal to ME, and consequently the arc of the circle described from the point M as a centre, and which will pass through the point E, will touch the first circle in N. To determine the other centre S, bisect the straight line EO, and from the point of bisection draw a perpendicular which will meet IG produced in the point S, which will be the centre of the arc EO. The arcs AQ and QR are described, the first round the point I as a centre with the radius IA; the second round any assumed centre with a radius equal to AI.

By M. de Palmi.

Another method is for determining the midship sections of flat-floored ships. It was invented by M. de Palmi of Brest. A rectangle ABIL (fig. 12) is described, which has for its breadth the breadth of beam, and for its height the depth to the keel. At E and F, the extremities of the flat of the floor, the perpendiculars GE and HF are drawn equal to the rising. A line KE (fig. 13) equal to LG is assumed, and a square described upon it; two quadrants of circles AQE and AXE are inscribed in this square, and either arc AXE is divided into a certain number of equal parts, AV, VX, XY, YZ, &c. drawing from the points of division VO, XN, &c. perpendicular to the radius AK. The depth of the vessel to the rising of the floor is divided into the same number of equal parts; and transferring to level lines drawn through these last points of division O, N, &c. the distances OS, NR, MQ, &c. intercepted in fig. 13 between the radius AK and the arc of the circle AQE, it only remains to pass a curve ASRQPE, in fig. 12, through the extremities of all the perpendiculars or ordinates OS, NR, &c. and the form of half the first section is obtained. ED may be formed by an arc of a circle touching the first curve E, and joining the side of the keel at D.

Fig. 12.

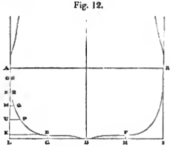
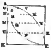


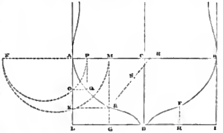
Fig. 13.



By Bouguer.

A third method, given by Bouguer, is for sharp ships. Form as before the rectangle ABIL (fig. 14), circumscribing the part of the section below the main breadth AB; then the rising GE or HF of the midship-floor is taken equal to a fifth or a sixth part of the flat of the floor GH. The points E and F being determined, two portions of parabolas AE and BF are described, A being the vertex and AC the axis of the one, and B the vertex and BC the axis of the other. The flat of the floor is formed by two arcs of circles, the convexity of the upper arc being below, and of the lower arc above. Having drawn from the point E, EK and EM perpendicular respectively to AL and AC, describe from a centre in AC produced indefinitely towards N, the semicircle MKN passing through the points K and M. Then AN will be the parameter of the parabola, which will serve to determine as many points in the curve as may be desired. If it be required to find a point in the vertical line PQ through which the curve will pass, it may be found by describing the semicircle NOP, and drawing from the point O, where the semicircle cuts AL, the horizontal line OQ, the point Q, the intersection of this line with PQ, will be a point in the parabola. In the same manner any number of points may be found. In order that the first arc of

Fig. 14.



the circle of which the flat of the floor is formed, may not make an angle with the parabola, it is necessary that its centre should be situated in some point S of the perpendicular to the parabola ER. To draw this perpendicular, the sub-normal must be made equal to half the parameter AN.

Methods for forming the body.

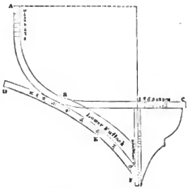
These methods are sufficient to show the nature of the mechanical systems of drawing the midship sections. We will proceed to give some of the mechanical systems of forming the sections of the fore and after bodies of ships. This operation affords a greater scope for ingenuity than the formation of the midship sections, and consequently the methods proposed have been much more numerous. The principal lines used in the construction of ships' bodies by these methods are the main breadth-lines, the top breadth-lines, and the rising and breadth-lines of the floors. These lines are shown in two planes, a longitudinal vertical plane, and a longitudinal horizontal plane. The rising of the main breadth-line shows the projection on the longitudinal vertical plane of the heights above the upper side of the keel, at which are the greatest breadths of the different vertical sections fore and aft; and the horizontal main breadth-line shows the corresponding distances from the middle line of the ship at the respective sections. The rising of the top breadth-line, and the horizontal top breadth-line, show in the same manner the heights from the upper side of the keel, and the horizontal distances from the middle line of the ship, of the different vertical sections at the top breadth of the timbers. At these heights, and at these distances from the middle line, arcs of circles are generally described, which give the form of parts of the vertical sections, or of the frames of the ship. The rising line of the floors gives in the same manner the heights above the upper side of the keel, and the horizontal breadth-line of the floors gives the distances from the middle line at which the floor-sweeps commence.

Whole moulding.

One of the oldest methods of forming a ship's body is that which is called "whole moulding." It is a method of constructing the square body, that is, all the body except the fore and after extremities of a vessel, where the planes of the frames are placed obliquely to the middle line, by means of two moulds; the upper one giving the form of the timbers above the rising line, and the lower one (called the "floor-hollow") giving the form of the timbers from the rising line to the keel. The midship section is first formed, usually by arcs of circles; and at the height of the rising line in this section a horizontal tangent is drawn to this curve. In order that this tangent may be horizontal, the centre of the arc, forming the lower part of the curve, must be in a vertical line passing through the point at which the tangent is drawn. The lower part is formed by a sweep which reconciles with the upper curve. Usually this sweep does not correctly touch the upper curve, although the inaccuracy is not very important in this method of construction. In forming the body-plan, the heights of the main breadth and rising lines at the different frames are set off, and the different sections drawn by the two moulds. On the horizontal part of the upper mould ABC (fig. 15) are marked the half main breadths of the different sections, as shown at C, and on the upper part of the mould their heights, as at A; the lower mould DEF is also marked where it meets the side of the keel at the different sections.

In moulding any timber, a square, called the rising square, with the heights of the different risings of the timbers marked on it, is used, by which the moulds are set according to the particular timber the form of which it is intended to obtain. On this square are also frequently marked the heights of the cutting down, by which the form of the inside of the timber is obtained at the same time. The operation of moulding a timber may be best seen by reference to the figure, where the moulds and rising square are set for moulding the lower futtock. No. 8.

Fig. 15.



Method by Duhamel.

In Duhamel's *Elémens de l'Architecture Navale*, there is a French method, nearly resembling this, of "whole moulding."

By Mungo Murray.

In Mungo Murray's Treatise on Ship-building, a method is given for forming a ship's body by the use of the sector. This instrument is formed of two scales connected by a hinge, so as to open and shut like a common rule. Seven lines are drawn on each leg of the sector from its centre, divided at numerous points, indicating lengths which refer to differents elements of the body. The marks on the corresponding lines on the two legs of the sector refer to the same distances.

The lines on one side of the sector are divided for the fore-body, and on the other for the after-body. The manner of using these lines is thus described. "The general dimensions being determined, and a scale adapted to the drawing, take the half breadth with a pair of compasses, and placing one foot in the proper point for the half breadth of the midship section, which is shown on one of the lines, open the sector till the other foot reaches to the same point in the corresponding line on the other leg."

The sector being thus set, the different distances are taken by the compasses from the corresponding points marked on the corresponding lines, and set off in the different plans.

It is immediately evident that, by the use of the sector as described, all ships constructed by it would be similar to that according to which the distances were marked on these lines. If it is required to form a fuller or a sharper body than that by which the lines of the sector were divided, the midship section, with the foremost and aftermost sections, must be determined agreeably to the will of the constructor; and the intermediate sections will be determined on the diagonals by setting the sector separately for each diagonal, and then taking the distances from the lines as before for the formation of the different plans in the drawing.

By Bouguer.

The next method of constructing ships' bodies which we shall give is described by Bouguer; the diagonals in this method are formed of arcs of ellipses. The midship section is formed at will, and the extreme sections, forward and abaft, are formed in an arbitrary relation to the midship section. To form the after-body by this method, let ABC (fig 16) represent the midship section, FED the after section, and BE the projection of one of the diagonals. Describe the arc of a circle BA (fig. 17) whose radius is equal to three times the line BE (fig. 16), and whose versed sine BC is equal to BE. Divide the sine AC into any

Fig. 16.

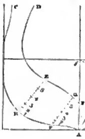
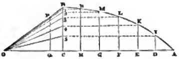


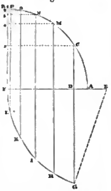
Fig. 17.



number of equal parts, according to the number of intermediate timbers it is intended to draw. From these points of division draw the lines DI, EK, &c. perpendicular to AC; and from the points where these lines intersect the arc of the circle draw I5, K4, &c. parallel to AC. Transfer the line BC, so divided at 1, 2, &c. to BE, in fig. 16, which will give points in which the intermediate sections will cut the diagonal BE. The other diagonals are divided similarly by taking any point O in AC produced (fig. 17), and joining OB, OI, &c. and placing the projection of any diagonal as PQ parallel to BC, and with its extreme points in OB and OC. Some constructors prefer dividing each diagonal separately, by describing arcs of circles BA with different radii; others, instead of dividing the sine AC into equal parts, divide the arc AB into equal parts, and then proceed as before.

The fore-body is formed by nearly the same means, but is always made fuller than the after-body. Let A*bc* (fig. 16) represent the midship section, and A*ed* the extreme section forward; produce the projection of the diagonal *be* to meet the middle line of the body-plan in *f*. Describe the quadrant of a circle BA (fig. 18) with a radius equal to *fb* (fig. 16), and draw the sine DC equal to *fe*, and parallel to FB. From a point E in FA produced, describe an arc of a circle, with a radius equal to once and a half or twice FB, according as it is intended to make the fore-body fuller or sharper, meeting CD produced in G. Divide the arc FG into as many equal parts as it is required to find spots on the diagonal *be*, for the intermediate sections; and from the points of division H, I, &c., draw HM, IN, &c. parallel to BF; and draw P1, O2, &c. parallel to FA. Then transfer BF, so divided, at 1, 2, &c. to *bf* in the body-plan, which will give points in which the intermediate sections will cut the diagonal *bf*. Instead of dividing the arc FG into equal parts, some constructors divide the sine DG into equal parts, and, by drawing lines parallel to FD from these points of division, determine the points of division of the arc FG, and then proceed as before. Instead of making similar figures for other diagonals, they are frequently divided proportionally to *fb*.

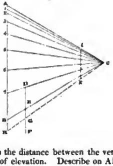
Fig. 18.



Bouguer proceeds to show the method of completing the diagonals before and abaft the extreme sections.

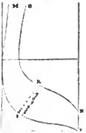
One of the easiest methods of constructing ships' bodies, is by means of an equilateral triangle, and is described by Duhamel in his *Elémens de l'Architecture Navale*. To construct the triangle for the after-body, draw any line AB (fig. 19), and divide it at the points 1, 2, 3, &c. so that the distance from 1 to 2 may be three times the distance A1, taken at pleasure, the distance from 2 to 3 five times A1, and so on; the number of points of division corresponding to the number of intermediate sections between the midship section and the stern-post, together with the after-section at the stern-post. Suppose the number of intermediate sections to be 7, let the distance from 7 to B be at least equal to the distance between the vertical sections on the plan of elevation. Describe on AB the equilateral triangle ABC, and join C1, C2, C3, &c. The use of this triangle is to divide the projection of the diagonals in the body-plan proportionally to the divisions of the base of the triangle AB.

Fig. 19.



In the plan of elevation, or sheer plan, take the distance between any two of the vertical sections, and place DE, the line representing this distance, parallel to AB, and so that its extremities may be in the lines C7 and CB. Produce DE to F, and take the horizontal distance from the intersection of the projection of the diagonal with the vertical section 7, to where the projection of the diagonal meets the projection of the after fashion-piece; and place this distance DG on DF, keeping one of its extremities in D; then join CG, and produce it to meet the base AB produced in H. Take the projection of this diagonal in the body-plan IK (fig. 20) from the midship section LIM to the fashion-piece NKO, and place it in the triangle parallel to the base AB, and with its extremities *i* and *k* in CA and CH; the lines C1, C2, C3, &c. will divide the line *ik* proportionally to the divisions of the base of the triangle AB. Transfer this line so divided to its place in the body-plan: the points 1, 2, 3, &c. will give spots through which the intermediate vertical sections will pass.

Fig. 20.



Some who have used this method of forming ships' bodies placed the projections of all the diagonals parallel to the base of the triangle; others placed them at different angles with the base. Duhamel recommends their being placed as follows. The projection of the lower diagonal representing the floor ribband parallel to the base; the projection of the second diagonal at an angle of

Chapman's Parabolic System.

60° 30′ with that part of the side of the triangle above the projection of the diagonal; the third at an angle of 68°; the fourth at an angle of 86°; the fifth at an angle of 65°; and the projection of the sixth or top-breadth ribband at an angle of 60°.

To construct the fore-body, a nearly similar process is adopted; but the base of the triangle is differently divided,—generally in a geometrical progression whose common multiplier is 2. The divisions of the bases of the triangles, however, are altogether arbitrary, as well as the angles of inclination at which the projections of the diagonals are placed, for both the fore and after bodies.

Objections to the use of such processes.

These are some of the most esteemed mechanical methods of constructing the midship sections of ships, and the fore and after bodies in relation to them. The inspection of them already shows that there is no attempt to describe a form which is proved to possess any property conducive to the good qualities of a ship. In forming a midship section by arcs of circles, it has been said that this figure has been chosen because a circle contains the greatest area under the least periphery. Supposing even that this principle were introduced into the form of a midship section, which is, however, frequently destroyed by the use of several arcs of circles, it by no means establishes the propriety of using the arcs of circles in the construction of the form of a midship section, because it would first be necessary to show that it would be a good property for a midship section to contain the greatest area under the least periphery. In fact, the principles of naval architecture require a contrary practice; a flatness is requisite in some parts of this section instead of rotundity, to give lateral resistance, great stability under a given area, and fine water-lines. The use of the ellipse is equally arbitrary. Little can be said in favour of either of the methods of designing bodies which we have described, nor need any thing be urged against them: it will evidently be perceived, that they are the resources of persons who are called upon to give designs of ships, and who, being ignorant of any correct data on which to form their design, are necessitated to adopt some such system of construction that they may designate as their theory. In no case do we find that those who have published systems such as the foregoing, attempt to prove that ships built after these systems are in consequence good ships; the utmost assumption appears to be, that by proceeding with a drawing after the course laid down, the result will be the design for the body of a ship. All such methods are to be deprecated, as being mere empirical substitutes for knowledge, and because they not only oppose a barrier to legitimate attempts towards improvement, but they actually prevent the application of such knowledge to the designing of ships' bodies, as may really be possessed. If we look upon systems for tracing these curves merely as aids to the well-informed naval architect in the formation of his drawing, they cease to be objectionable, and become mere mechanical means in his hands, which he can use or vary at pleasure, for the purpose of facilitating the mechanical operations incidental to the designing of a ship. They are also necessarily introduced into this article, as forming an essential feature in the progressive improvement of naval architecture. Mechanical methods of constructing designs for bodies followed, no doubt, immediately upon the method of constructing them merely by the aid of the eye, and they continue to be very generally used in the merchant-service, and may, no doubt, be reckoned among the causes which have operated so injoriously to the interests of our mercantile navy.

### *Chapman's Exponential and Parabolic Systems of Construction.*

These were described in the last work of the celebrated Swedish naval architect Chapman; it was published in 1806. The parabolic system must be classed in this division of our subject, as among the mechanical methods of designing the forms of ships, though it is so incomparably beyond all those plans which we have previously described, that we shall devote some space to a detailed description of it. The Swedish work, until translated by the late Mr Morgan, a member of the School of Naval Architecture, in the Papers on Naval Architecture, was only known to English ship-builders as Chapman's "large work;" a name acquired in consequence of a large folio of plates that accompanies the letter-press, which is in comparison not very voluminous.

Chapman's Parabolic System.

Chapman's work translated in Papers on Naval Architecture.

From this translation, and from a paper on the same work by a Swedish naval engineer, Captain Carlsund, unfortunately for the science of naval architecture, also dead, we shall give a synopsis of the system of construction at present adopted by the northern powers of Europe.

Criterion of the qualities of ships.

Chapman commences his investigation by assuming a case, which he presumes may be taken as a criterion of the qualities of ships. This case is an engagement between hostile fleets. These he supposes to be ranged in lines parallel to and within gunshot of each other, and also in such a direction with respect to the wind that they lie within six points of it, each succeeding ship sailing in the wake of the ship a-head, about fifty fathoms apart, in a stiff top-sail breeze, and under the three top-sails, top-gallant sails, fore-topmast stay-sail, jib, and driver. They are supposed, when under these circumstances, not to incline more than seven degrees, and must be capable of fighting their leeward lower-deck guns with a heavy sea running; be good sailers, and work well to windward; so that although the ships may be of different sizes, and carry different weights of metal, yet, in equally high wiods, and under similar sail, their angles of inclination being nearly the same, their guns may be worked with equal convenience, they may be all equally efficient in point of velocity, and under all circumstances manœuvre with equal facility. Chapman then says, of two hostile fleets opposed to each other, the fleet which is composed of the stiffest and best-sailing ships is master of the attack, and can begin and end it at pleasure. But that, as the operations of many such ships together, although of different sizes, should at once produce the same effect as if they constituted but one machine, it is necessary that they should keep in company, and be effective in proportion to their size. As they must sail equally well, the area of their sails must be proportional to the resistance they experience from the water; and as all the guns must be used and worked with like advantage, their inclination must be nearly the same, so that the form of the ships below the water will be in some degree adapted to the same area of sails; hence it is found, that when a ship of the line is to be constructed, the body of the ship and the sails are to be considered as constituting the ship. Chapman points out the difficulties which oppose themselves to the designing bodies which are thus to act together, beyond those which present themselves in the case of designing ships intended to sail and act singly; and he observes, that although all the rules of art may be attended to in the design of a ship, it may happen that she will not behave well, and this for the following reasons: If the sails are badly cut and made, so that the wind is prevented from producing its full effect on them, by which not only the sailing close-hauled is injured, but also, the facility of working, and consequently of manœuvring, is diminished; also, that the behaviour of a ship under sail may be very much deteriorated as regards her weatherly qualities, and her ease and quickness of working, if all the sails are not set advantageously, both in respect to the direction of the wind, and also of the ship's course. And, again, it is absolutely necessary that great attention should be paid to the trim of the ship, and to the adjustment of the positions of the masts, which have a great effect on a ship's qualities. Such, he says, are the reasons why it so frequent-

Ships and sails to be considered together.

Trim of a ship.

ly happens, that a ship may in one voyage possess very bad, and in another very good qualities, or at one time be a very bad sailer, and at another a very good sailer.

The natural inference from this is, that although the form of a ship should be that which is the best adapted for all that may be necessary to the service for which she is intended, it by no means follows that such a ship shall realize the intentions of her constructor, unless she be equipped and commanded by persons equal to the task of properly developing her qualities.

Economy to have large ships and heavy metal.

He then proves that, by assuming the load displacements, the crew and provisions as the expense, and the weight of a round of shot as the effect, that it is the greatest economy to have large ships and heavy metal. Repeating the observation already made, that all ships forming a line-of-battle, although of different sizes, must act as parts of the same machine, and must consequently have the same qualities, which cannot be effected if the ships be similar, it follows that the rules by which they are designed must be of such a nature that they shall be capable of giving similar qualities to dissimilar ships.

Displacement dependent on armament.

He says the displacement is dependent wholly on the total weight of the armament, and then considers the various items making up the total displacement. It consists of the weight of the armament, and of every thing connected with it; then the weight of the ballast, which is in proportion to the armament.

Ballast.

Ballast, he says, is necessary for a ship of the line, in order to preserve its qualities at the end of a long voyage, when the greater part of the provisions and ammunition will have been consumed. Also, as these weights are so considerable that the ship may be lightened to such an extent that her centre of gravity may not only rise a foot higher above the water from this diminished immersion than it was at the commencement of the cruise, but will rise so much the more from the influence this diminution of the weights in the hold will have in elevating its position, the stability is also necessarily diminished. It is therefore proper, in order that this loss of stability may not be too great, to have such a quantity of ballast that the remaining weight in the hold may not be too little in relation to the constant weight above the water. And also, he says that the consideration that a ship necessarily lightens from the consumption of stores, renders it necessary that all the calculations which relate to her stability should be made in relation to a water-line, assumed as that which she would have after the expiration of about a quarter of the cruise; and it should be from this water-line that the masts, &c. should be determined.

The next component of the displacement consists of the provisions, which are in proportion to the crew, and therefore to the armament; and, lastly, the ship, with her masts, yards, rigging, anchors, cables, fitting, &c. &c.

Length and breadth.

Having determined the displacement required for the armament, the next considerations are the length and breadth. These have hitherto been determined by the number of ports, the space between them, and the space forward and aft; but they should be determined from the displacement, for the product of the number of guns into their weight determines the displacement, therefore the displacement determines the length. If the length resulting from this be considered too great for the number of ports, it is because the sum-total of the weights of the guns being given and constant, it follows that if each gun be of greater weight of metal, the number is smaller; and if each gun be of less weight of metal, the number is larger; but the length of the ship is nevertheless the same.

Resistance.

It appears that, from experiments made in Sweden in the year 1794, it was determined that the effect of the water on the after-end of a body, in opposing its progress, is a minimum when the surface of the body makes an angle of 13° 17′ with its middle line, and that consequently Chapman designed the after-bodies of his ships in accordance with this result.

General rule for length and breadth.

In order to form general rules, according to the exponential system, for deducing the length and the breadth from the displacement, he proceeded in the following manner. The greatest breadth at the water-line for all line-of-battle ships is called B; and the length of the "construction water-line," which term will be afterwards explained, is called *l*. Then, he says, "designs of two classes of ships composing the line-of-battle were constructed with great care, and the following table formed."

| | 110 | 94 | 66 |
|---|---|---|---|
| Displacement, D.......... ... = | 152875 | 128297 | 88722 |
| Length, *l*.......................... = | 207·59 | 196·65 | 175·48 |
| Breadth, B......................... = | 56·27 | 53·32 | 48·46 |

In finding the length *l* from the displacement for all ships of the line, the ships of ninety-four and sixty-six guns have been used. Put therefore 128297 = D, and 88722 = *D*, also 196·65 = l and 175·48 = *l*, where it will be seen that the Roman characters are used for the larger ship, and the Italic for the smaller. Then from the foregoing reasoning the following proportion is deduced, that

$$\mathrm{D}^v : D^v :: \mathrm{l} : l \text{; hence}$$

$$\text{the exponent } v = \frac{\log.\ \mathrm{l} - \log.\ l}{\log.\ \mathrm{D} - \log.\ D}$$

$$= \frac{\log.\ 196{\cdot}65 - \log.\ 175{\cdot}48}{\log.\ 128297 - \log.\ 88722}$$

196·65....................2·2936940  128297..........5·1082165
175·48....................2·2442276  88722...........4·9480313

0·0494664  0·1601852

$$\frac{0{\cdot}0494664}{0.1601852} = 0{\cdot}3088 = v$$

2·2936940
5·1082165×0·3088=1·5774172

0·7162768...5·2033 = the co-efficient.
2·2442276
4·9480313×0·3088=1·5279520...5·2033 = the co-efficient.

Thus the length $l = 5{\cdot}2033\ \mathrm{D}^{0{\cdot}3088}$ is obtained for all the line-of-battle ships.

To find the breadth B from the length *l* for three-decked ships the same method is used. Thus, the exponent for 110 and 94 gun ships, $v = \frac{\log.\ 56{\cdot}27 - \log.\ 53{\cdot}32}{\log.\ 207{\cdot}59 - \log.\ 196{\cdot}65}$ $= 0{\cdot}9947$; and as the co-efficient is found to be a divisor $= 3{\cdot}5863$, the breadth B for all three-decked ships of the line $= \frac{l^{0{\cdot}9947}}{3{\cdot}5863}$.

To find the breadth B from the length *l* for two-decked ships. The exponent $v$ of ships of 94 and 66 guns, $= \frac{\log.\ 53{\cdot}32 - \log.\ 48{\cdot}46}{\log.\ 196{\cdot}65 - \log.\ 175{\cdot}48} = 0{\cdot}8391$; and as the co-efficient is a divisor $= 1{\cdot}5767$, the breadth B for all two-decked ships of the line $= \frac{l^{0{\cdot}8391}}{1{\cdot}5767}$; according to which the following table is calculated.

| | 110 | 94 | 80 | 74 | 66 | 52 |
|---|---|---|---|---|---|---|
| Displacement, D = | 152875 | 128297 | 107400 | 96422 | 88722 | 66753 |
| Length, *l*.......... = | 207·59 | 196·65 | 186·15 | 180·05 | 175·48 | 160·72 |
| Breadth, B.......... = | 56·27 | 53·32 | 50·92 | 49·51 | 48·46 | 45·01 |

Having explained the method of determining the principal dimensions, we shall refer for a description of the parabolic system of construction to the paper we have already

Chapman's Parabolic System.

mentioned as having been written by a Swedish naval engineer, Captain, then Lieutenant Carslund. It says,

Whether sections of ships follow a general law.

Chapman endeavoured to discover whether or not the areas of the several transverse sections in well-constructed ships followed any law; and if so, to find that law. For this purpose he calculated the areas of the sections of several ships; and in order to make the numbers more convenient, he divided these areas by the breadth of the midship section; then, at their respective stations on the drawing, setting off from the water-line, distances equal to the quotients, he traced a curve representing the areas. This curve he called the curve of sections. He then endeavoured to find the equation to the curve, or rather that of another curve which would coincide with this for the greatest length; and he found, that if the power and parameter of a parabola were so determined as to allow that curve to pass through three given points of the curve of sections, the two curves would nearly coincide. In the fore-body the three points were taken; one forward, one at the midship section, and one midway between. In the after-body the points were similarly situated. In some ships the exponent to the curve was higher in the after-body than in the fore-body, in some it was the same for both. It was also found that there were ships in which the curve of sections almost exactly agreed with the parabola, and these ships invariably bore excellent characters. Chapman consequently concluded, that if the areas of the several sections of a ship were made to follow the law of the abscissas of a parabola, a vessel possessing good sailing qualities might be formed, and the process of construction much simplified.

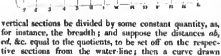
Curve of sections.

This account shows that the method is applicable to all sorts of constructions, as it only requires that the relative areas of the sections shall decrease from the midship section towards the extremities in a certain relation, which can be varied to infinity; it is therefore equally useful in constructing the sharpest man-of-war as the fullest merchant-man.

To construct the curve of sections.

Suppose a ship is found to answer well at some given water-line, AC (fig. 21). Let the areas of the transverse vertical sections be divided by some constant quantity, as, for instance, the breadth; and suppose the distances *ab*, *cd*, &c. equal to the quotients, to be set off on the respective sections from the water-line; then a curve drawn through the points *b*, *d*, &c. will be the curve of sections. It will be found to be convex to the water-line at the extremities.

Fig. 21.



The order of the parabola which coincides for the greatest distance with this line may easily be found.

To find the assimilating parabola.

Let the general equation to the parabola be expressed by $y^n = ax$; then it is always possible to determine $n$ and $a$, so that the parabola shall pass through two points besides the vertex. Any two points between $b$ and C may be taken, but it is evident that the farther apart the three points are taken, the longer will the parabola coincide with the line of sections. Of course, neither point may be in the convex part of the line of sections. It will be found that the point $g$ at the foremost frame, and $h$ in the middle between $g$ and $b$, are the points which should be taken.

Draw a tangent to the curve at the point $b$, which will be parallel to the water-line; then $mh$ and $ng$ are abscissas, $bm$ and $bn$ ordinates to a parallel passing through $b$, $h$, and $g$; put $mh = x'$, $ng = x''$, $bm = y'$, and $bn = y''$; then, substituting these values in the equation to the parabola, we have

$$y'^n = ax', \text{ and } y''^n = ax'',$$

$$\text{or } n \log. y' = \log. a + \log. x', \text{ and}$$

$$n \log. y'' = \log. a + \log. x'';$$

$$\text{hence } n = \frac{\log. x' - \log. x''}{\log. y' - \log. y''}$$

$$a = \frac{y'^n}{x'},$$

$$\text{and } \log. a = \frac{\log. x' \cdot \log. y'' - \log. x'' \cdot \log. y'}{\log. y' - \log. y''}.$$

We have now the values of $n$ and $x$, and by calculating several other abscissas, we can trace the parabolic curve. The same operation applied to the after-body will give the exponent and parameter of the parabola, which is the most similar to the curve of sections in that body.

It generally happens that the exponents are nearly the same in both bodies, if the place of the midship section be determined in the manner to be shown in the sequel.

It will be found that the parabola and the line of sections very nearly coincide, the former being sometimes a little within the latter between $g$ and $h$, and without at the foreside of $h$, and sometimes, but much more seldom, the contrary. The parabola always cuts the water-line at a short distance from the rabbets, this distance being rather greater forward than abaft.

This system applied to American ships.

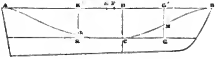
Several American ships of war have been submitted to this method of investigation, which was found to answer very well with their bodies. Indeed there can be no great deviation, as the parabola varies according to its exponent and parameter; if the ship is full, a large exponent adapts it to that shape; and if the ship is lean, a small one. If the body has a long straight of breadth, and sharpens quickly at the extremities, by deducting a part in midships from the comparison, the system may still be applied; or if, as is the case generally with English merchant-ships, there is a very great draught of water in proportion to the breadth, by deducting a part from the water-line downwards, this method may be applied to the remainder.

From this reasoning, it appears that ships may be constructed to coincide exactly with the parabolic line, without deviating from the forms which experience has proved to be the most conducive to giving ships good qualities. Chapman stated that this would most probably be superior to the old system, and the result has confirmed his statement; for ships of the line, frigates, and merchant-men have been constructed after it, all of which have been very fine vessels.

Displacement.

From the manner in which the curve of sections is formed, it follows that its area multiplied by the breadth is equal to the displacement, and that the centre of gravity of the area is in the same transverse section as the centre of gravity of the body; but the area of this curve, supposing it to be a parabola of a certain power, is a known part of the rectangle formed by the greatest ordinate and the abscissa; hence, by making the areas of the sections decrease in the ratio of the abscissas in the parabola, we obtain certain equations between the quantities. To find these equations, suppose the parabolic line, now also representing the line of sections, to be ACB (fig. 22), cutting the water-

Fig. 22.



line at some distance from both rabbets; let C be the place of the midship section, and DC the greatest abscissa. Put $AB = l$ and $DC = d$, let the exponent of the parabola before and abaft $= n$, and the displacement $= D$; then the area of the parabolic line BDACB $= \frac{n}{n+1} \cdot l \cdot d$, and the displacement $\frac{n}{n+1}\, l \cdot d \cdot B$ (B representing the breadth); but $dB =$ area of the midship section; hence $\frac{n}{n+1} \cdot l \cdot$ (*area of midship section*) $= D$............(1).

Midship section before middle of length.

Let E be the middle point of the water-line AB, which we may call the construction water-line, F the place of the centre of gravity in point of length; let ED, the distance the midship section is before the middle of the water-line, $= k$, and EF, the distance the centre of gravity is before the middle, $= a$. We will now determine the place of the midship section in reference to the situation of the centre of gravity F.

As BCD represents the displacement of the fore-body, and CDA that of the after-body, the moments of these two parts will give the common moment.

The centre of gravity of the parabolic area is at a distance from the abscissa DC

$$= \frac{n+1}{2n+4} \times \text{the ordinate DB},$$

and for the parabolic area DCA it

$$= \frac{n+1}{2n+4}\,\mathrm{DA}.$$

The moment of DCB from the point E

$$= \left(k + \frac{n+1}{2n+4} \cdot \mathrm{DB}\right) \cdot \mathrm{DCB},$$

and the moment of DCA from the same point

$$= \left(\frac{n+1}{2n+4} \cdot \mathrm{DA} - k\right) \mathrm{DCA}.$$

But the areas DCB and DCA are proportional to DB and DA, and the sum of the above moments $= \mathrm{EF} \cdot \mathrm{BCA}$, or $a \cdot l$, $l$ representing the area; hence

$$al = \left(k + \frac{n+1}{2n+4}\,\mathrm{DB}\right) \mathrm{DB} - \left(\frac{n+1}{2n+4} \cdot \mathrm{DA} - k\right) \mathrm{DA}$$

$$= -\frac{n+1}{2n+4}\left(\mathrm{DA}^2 - \mathrm{DB}^2\right) + k\left(\mathrm{DB} + \mathrm{DA}\right)$$

$$= (\mathrm{DA} + \mathrm{DB}) \cdot \left(-\frac{n+1}{2n+4} \cdot (\mathrm{DA} - \mathrm{DB}) + k\right);$$

but $\mathrm{DA} - \mathrm{DB} = 2k$, and $\mathrm{DA} + \mathrm{DB} = l$; hence

$$al = lk \cdot \left(1 - \frac{n+1}{n+2}\right),$$

$$a = k \cdot \frac{1}{n+2},$$

$$\text{or } k = a \cdot (n+2) \text{............(2).}$$

That is, if the midship section DC is placed at such a distance $k$ from the middle point of the construction water-line, the centre of gravity will be in the point F assigned to it.

These two equations (1 and 2) form the principal foundation of the parabolic method of construction. In the first equation, any quantity may be known by assigning values to the others; and in the second, by fixing a value for the distance of the centre of gravity before the middle, the place of the midship section will be known. Then, having by the first equation found the exponent of the parabola, any abscissa GH or KL may be calculated. Suppose, for instance, GH to be required; then in the first assigned equation $y^n = ax$, $n$ is known; also $y$ and $x$ are known for a certain point B, through which the parabola passes; the value of $y$ for this point is DB, and of $x$ is DC. This gives

$$a = \frac{\mathrm{DB}^n}{\mathrm{DC}}$$

$$= (\text{by cutting DB} = f)\, \frac{f^n}{d} \text{....(3).}$$

Now GH is easily determined in the above equation, by assigning a value to CG; if CG or any other ordinate is expressed by $y'$, the corresponding abscissa $\mathrm{GH} = x'$ is determined by the equation

$$x' = \frac{y'^n}{a} \text{......(4).}$$

This equation is sufficient for calculating the areas of all the sections for the fore-body; and for those of the after-body we have the equation (3), in which, by substituting $f$ for DA, we get the value of the parameter $a'$ of the parabola of the after-body; and substituting this value for $a$ in equation (4), and giving to $y'$ any value CK, a corresponding abscissa LK is obtained. And in the same manner as many may be found as may be thought proper. It is evident that GH and LK must be subtracted from the largest ordinate DC, to give G'H and K'L, which represent the areas of the corresponding sections.

This method of first calculating the abscissas, and then subtracting them, may appear indirect, as the true lines G'H and K'L could have been obtained at once by transforming the equation of the parabolic line to another, beginning at the point D; but it would then have lost its simplicity, and the calculations would not have been easier than by this method. One thing may, however, be done, which is to substitute the area of the midship section instead of its quotient by the breadth, by which the whole areas of the other sections will be obtained, instead of the lines which represent them.

The principles of the parabolic method being now explained, it will be easily seen how very useful its application is to the comparison of all ships, whether they were constructed with or without reference to it.

Exponent of the line of sections.

By referring to equation (1), we find that the displacement, area of midship section, and the construction water-line, being known, the exponent of a parabola that coincides most nearly with the line of sections is easily found; and we shall have (putting M for the midship section) the value of

$$n = \frac{\mathrm{D}}{l\mathrm{M} - \mathrm{D}} \text{.......}(a).$$

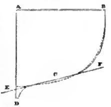
This value of $n$ shows the degree of fulness of the ship.

The parabolic method may also be applied to show the relative fulness of the midship section, of any of the water-lines, of the displacement with respect to the water-line, and of several other elements.

Exponent of midship section.

Let ABC (fig. 23) represent a midship section, and let EF be a tangent to the curve at the point of contrary flexure C; the small area ECD not being of any importance, may be neglected. If the midship section is at all similar to those usually given to ships, a parabola may be assigned which shall pass through the points B and C, and have nearly the same area with the midship section, and also nearly coincide with the curve, so that the exponent will afford means of ascertaining its relative fulness.

Fig. 23.



Chapman's Parabolic System.

Call the breadth of the water-line $AB = \frac{1}{2}B$, the depth $AE = h$, and the area $ABE = \frac{1}{2}M$, and let $m$ be the exponent of a parabola having the same area; then

Exponent of the midship section.

$$\frac{m}{m+1} \cdot \tfrac{1}{2}B \cdot h = \tfrac{1}{2}M,$$

$$\text{and } m = \frac{\frac{1}{2}M}{\frac{1}{2}Bh - \frac{1}{2}M} = \frac{M}{Bh - M} \ldots\ldots\ldots(5).$$

In the same manner, the exponent may be found for the water-line, by supposing a parabola with its vertex as the greatest breadth, and passing through the points in which the water-line cuts the middle line. Suppose the exponent of this parabola $= r$, the length on the water-line $= L$, and, as before, the breadth $= B$; also let the area of the water-line $= W$; then

Exponent of the water-section.

$$\frac{r}{r+1} \cdot L \cdot \tfrac{1}{2}B \cdot = \tfrac{1}{2}W,$$

$$\text{and } r = \frac{W}{BL - W} \ldots\ldots\ldots(6).$$

Lastly, suppose the areas of the several water-lines, from the load water-line downwards, to decrease in the proportion of the abscissas to a parabola; and let the exponent $= s$, the depth from the water-line to the tangent of the midship section $= h$, the displacement $= D$, and the area of the water-line $= W$; then

Exponent of the displacement.

$$\frac{s}{s+1} \cdot Wh = D,$$

$$\text{and } s = \frac{D}{hW - D} \ldots\ldots\ldots(7).$$

By calculating these different exponents for ships already built, and which have been found to possess good qualities, a very correct idea of their shape will be obtained, which, in making new constructions, may be referred to; and after a very short practice the constructor will be enabled to determine, not only the principal dimensions, but the outlines of the body, before a drawing is begun.

Values of these several exponents.

A collection of such calculations was begun by Chapman, and has since his time been considerably augmented. We now therefore know what the value of the exponents ought to be in the different classes of ships, for the services to which they are destined. It is always found that large ships are fuller than small ones, and in consequence have larger exponents; and that merchant-men have larger exponents than men-of-war of equal size.

The exponent of the line of sections in the Swedish navy, in ships of the line, varies from 2·5 to 2·7; of the midship section, from 5 to 3·8; of the water-line, from 6·6 to 5·9; and of the displacement, from 2·2 to 1·8; of course the larger exponent belongs to the larger class of ships.

In frigates, sloops, and brigs, they are smaller; the exponent of the line of sections varies from 2·3 to 2·1; of the midship section, from 3 to 1·9; of the water-line, from 5·2 to 3·25; and of the displacement, from 1·6 to 1·25. These exponents show that small ships have much larger dimensions in proportion to their displacements than large ones.

The above results were obtained from the displacements and breadths, not including the plank; and the length is that of the construction water-line, which, in Swedish ships, is $\frac{1}{24}$th less than the whole water-line between the rabbets, $\frac{7}{10}$ths of which deduction is made from forward, and $\frac{3}{10}$ths from aft. In finding the exponent for the water-line, its whole length between the rabbets is taken.

These calculations are equally applicable with the plank on as with it off; in the first-mentioned case, the sections near the extremities will have, relatively to the midship section, a larger area, and there will therefore be scarcely any hollow at the ends of the curves, and it will not be improper to take the length of the water-line the whole length between the rabbets.

The following tables are given as an illustration of this method, in its application to English ships.

| | Length on the Water-line. | Breadth, extreme. | Depth from the Water-line to the lower edge of the Rabbet. | Displacement, including the Plank. | Area of the Load Water-section. | Area of the Midship Section. |
|---|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | Cub. Feet. | Sq. Feet. | Sq. Feet. |
| Nelson..... | 203·3 | 53·5 | 23·5 | 165182 | 10027 | 1099 |
| Bulwark... | 180·3 | 49·0 | 19·6 | 105584 | 7706 | 791 |
| Endymion | 157·0 | 41·9 | 16·0 | 55807 | 5656 | 510 |

Then from the equations ($a$), (5), (6), and (7), the following results may be obtained:—

Application of the system to English ships.

| | Value of $n$, the Exponent of the Line of Sections. | Value of $m$, the Exponent of the Midship Sections. | Value of $r$, the Exponent of the Water-line. | Value of $s$, the Exponent of the Displacement. |
|---|---|---|---|---|
| Nelson.......... | 2·836 | 6·9447 | 11·6034 | 2·3445 |
| Bulwark........ | 2·851 | 4·4141 | 6·6273 | 2·2538 |
| Endymion...... | 2·300 | 3·1795 | 5·1235 | 1·6088 |

From this table of exponents we may judge with certainty of the shape of the vessels. The Nelson, for instance, has a very full midship section, and an exceedingly full water-line; but she is not relatively so full towards the extremities as the Bulwark, and her displacement is not relatively much fuller than that of the Bulwark. The Bulwark has a small midship section, is full towards the extremities, and has a very large water-section in proportion to her displacement. The Endymion is a very sharp ship of her class, has a small midship section, is rather clean towards the extremities, but her water-line is not very sharp; its proportion to her displacement is very large.

The four exponents which have been described will, separately, only show the degrees of fulness in one direction; but they may be combined in such a manner as to express at the same time the longitudinal and transversal fulness; to effect which the value of the area of the midship section $= \frac{m}{m+1} \cdot Bh$ must be substituted in equation (1), which gives

$$\frac{n}{n+1} \cdot \frac{m}{m+1} \cdot l \cdot B \cdot h = D \ldots\ldots\ldots(b);$$

also, by substituting the value of $W = \frac{r}{r+1}$ BL in equation (7), we have

$$\frac{r}{r+1} \cdot \frac{s}{s+1} \cdot L \cdot B \cdot h = D \ldots\ldots\ldots(c).$$

In these equations the products $\frac{n}{n+1} \cdot \frac{m}{m+1} \cdot \frac{r}{r+1} \cdot \frac{s}{s+1}$ show the relative fulness of the different ships in comparison to the circumscribing parallelopiped. When the construction water-line is equal to the whole water-line, as was supposed in calculating the foregoing table,

$$\frac{n}{n+1} \cdot \frac{m}{m+1} = \frac{r}{r+1} \cdot \frac{s}{s+1}$$

By this equation any error in determining the exponents may be detected; and also by using the whole equations ($b$) and ($c$), errors in the dimensions or exponents will be detected.

Methods of interpolation for finding other elements.

By a method of interpolation, formulæ of very easy application have been deduced; by which the depth of the centre of gravity of the displacement below the water-section, the height of the metacentre, and several other essential elements, may be approximated to without the usually long calculations; and thus most of the qualities of a ship which are determinable by calculation may be ascertained, compared, and altered with very little trouble, before the construction is begun.

Application of the method to practice.

In order to apply this method of construction to practice, nothing more is requisite than to know the limits between which the exponents generally are for the class of ships in question, the proportion between the principal dimensions, and the distance the centre of gravity should be before the middle of the load water-line. In Swedish ships of the line and frigates, the distance of the centre of gravity of the displacement before the middle of the load water-line is between $\frac{1}{70}$th and $\frac{1}{80}$th of the length, and in smaller vessels it is a little more, depending on the manner in which their stores and rigging are distributed. This distance being determined, the weight the ship is to carry, the weight of the hull, and the relative proportions of the different dimensions, or the value of the exponents, the calculations will give the areas of every section, leaving the constructor the power of giving them whatever form he may wish.

Example of its application.

Captain Carlsund was employed in this country in building steam-boats for the Swedish post-office service. He has given the calculations of one of these boats, which were all constructed on Chapman's parabolic system, as an example of its practical application.

Suppose the ratio of the breadth to the length to be $\alpha$, and that of the breadth to the depth to be $\beta$; by substituting them in the equation (*b*), it will become

$$\frac{n}{n+1}\cdot\frac{m}{m+1}\cdot\alpha\cdot\beta\cdot B^3 = D.$$

The values of $m$ and $n$ are known, being assumed from former experience; the displacement is determined by the weight of the engines, added to the weight of the stores, &c. and an approximation to the weight of the hull. By assigning values to $\alpha$ and $\beta$, the value of B is obtained, and from that the values of the length and depth. The dimensions being now known, the scantling may be determined, and the true weight of the hull estimated; which, if very different from the approximation which was used, will cause a corresponding alteration in the dimensions, &c. With a steam-boat the stability is of minor importance, therefore it is not necessary to refer to equation (*c*).

The vessel in question was intended for two twenty-five horse-power engines, the weight of which, with the necessary stores, and the other articles, was estimated to be about 2050 cubic feet of water, and the approximation which was at first made to the hull was 1850 cubic feet, which supposed the whole displacement to be 3900 feet.

The vessel was intended to be sharp both at the midship section and at the extremities; hence $n$ was taken $= 2\cdot12$, and $m = 3\cdot0$; the proportion between the length and the breadth, or $\alpha$, was taken $= 5\cdot25$; and that between the breadth and the depth, or $\beta$, $= 0\cdot32$. By substituting this value in the equation, we have

$$B = \sqrt[3]{\frac{3900\times3\cdot12\times4}{2\cdot12\times3\times5\cdot25\times0\cdot32}} = 16\cdot58.$$

$$\text{Length} = 5\cdot25\,B = 87\cdot04,$$

$$\text{Breadth} = 0\cdot32\,B = 5\cdot31.$$

By calculating the weight of the hull according to these dimensions, it was found that the approximation was too small by 175 cubic feet. By adding this quantity to the displacement, and retaining the other values, it will be found, from the above equation, that the

$$\text{Breadth} = 16\cdot822,$$

$$\text{Length} = 5\cdot25\times16\cdot682 = 88\cdot315,$$

$$\text{Depth} = 0\cdot32\times16\cdot882 = 5\cdot383.$$

The weight of the engine, its situation, and that of its centre of gravity, must determine the place of the centre of gravity of the vessel, which was found to be about 2·25 feet before the middle of the length on the construction water-line; and consequently, from equation (2), the situation of the midship section was determined to be 9·27 feet before the middle of the construction water-line.

The stations of the other sections were determined by the room and space. The parameters for the fore and after bodies were first determined by substitution in the equation (3). In the fore-body

$$f = \frac{l}{2} - k = \frac{88\cdot315}{2} - 9\cdot27 = 34\cdot887,$$

and in the after-body

$$f = \frac{l}{2} + k = 53\cdot427.$$

The area of the midship section, from equation (5),

$$= \frac{m}{m+1}Bh = \tfrac{3}{4}\times16\cdot822\times5\cdot383,$$

$$= 67\cdot912 \text{ square feet,}$$

and the half area $= 33\cdot956$.

Hence, by equation (3), the parameter of the fore-body

$$= \frac{\overline{34\cdot887}|^{2\cdot12}}{33\cdot956} = 54\cdot895;$$

and for the after-body,

$$a' = \frac{\overline{53\cdot427}|^{2\cdot12}}{33\cdot956} = 135\cdot499.$$

The calculations for the sections are contained in the following table.

For the Fore-body, $x\ \frac{y^{2\cdot12}}{54\cdot895}$.

| Sections. | | Abscissa, or $x$. | Half the Midship Section, — $x$. |
|---|---|---|---|
| Name. | Distance from the Midship Sect. or $y$. | | |
| | Feet. | Square Feet. | Square Feet. |
| End | 34·89 | 33·960 | ·0 |
| $x$ | 32·24 | 28·730 | 5·23 |
| $u$ | 30· | 24·660 | 9·30 |
| $q$ | 24· | 15·360 | 18·60 |
| $m$ | 18· | 8·349 | 25·611 |
| $h$ | 12· | 3·535 | 30·425 |
| $d$ | 6· | ·813 | 33·147 |
| Midship section. | 0· | ·0 | 33·96 |

For the After-body, $x = \frac{y^{2\cdot12}}{135\cdot499}$.

| Sections. | | Abscissa, or $x$. | Half the Midship Section, — $x$. |
|---|---|---|---|
| Name. | Distance from the Midship Sect. or $y$. | | |
| | Feet. | Square Feet. | Square Feet. |
| End | 53·43 | 33·960 | ·0 |
| 34 | 50·76 | 30·460 | 3·50 |
| 32 | 48· | 27·060 | 6·90 |
| 28 | 42· | 20·390 | 13·57 |
| 24 | 36· | 14·700 | 19·26 |
| 20 | 30· | 9·990 | 23·95 |
| 16 | 24· | 6·225 | 27·735 |
| 12 | 18· | 3·382 | 30·578 |
| 8 | 12· | 1·432 | 32·528 |
| 4 | 6· | ·329 | 33·631 |
| Midship section. | 0· | ·0 | 33·96 |

Timber.

The areas of the sections being thus determined, the construction of the draught was begun. The midship section, and one or two sections in each body, being drawn in, and their areas ascertained to agree with the tables, one or two diagonals were got in, and the rest of the sections drawn, always keeping their areas precisely equal to those given by the table. The direction of the diagonals at the extremities determined the places of the rabbets of the stem and stern-post, and from these the length of the whole load water-line was found to be 0·44 feet longer than that of the construction water-line; that is, 0·33 at the fore-end, and 0·11 at the after-end; consequently the length of the load water-line between the rabbets was equal to 88·755 feet.

As, in a ship constructed according to this method, the situation of the centre of gravity with respect to the length, and also the displacement, are known correctly, during the progress of the work much tedious arithmetical calculation is avoided; and, after a very little practice, it will be found that the forms of the different sections may with great ease be drawn to contain the requisite areas; consequently, by the general adoption of the method, an amazing saving of time and trouble would be effected.

There can be no doubt that this parabolic system offers great advantages, especially to the student of naval architecture, in the great facility with which it may be applied to institute comparisons between ships by means of the exponents. The mere repetition of the digits which number the displacement of a ship, or the area of either of her sections, will convey no idea of the form either of the body or of the section. Again, the ratio of the displacement, or of the area of the section, to that of the circumscribing parallelopiped or rectangle, will convey a scarcely more definite idea of shape; whereas the exponent of the displacement or of the section, presenting itself to us not only as an arithmetical measure of quantity, but referring us at the same time to a geometrical line, the mind becomes immediately almost as conscious of the peculiarities of the form of the body or of the section as if a drawing of either were present before the eye. A very slight attention to the comparisons which have been drawn between the Nelson, Bulwark, and Endymion, by means of their exponents, will convince the reader of the advantage which the system possesses in this respect, and of the value in which an extensive digest of ships of various forms and qualities, calculated on this principle, would be held by naval architects. At the same time, it is quite evident that even the inventor, Chapman, would not have recommended the parabolic system as a total substitute for the more rigorous applications of science, but only as accessory to them. Also, the parabola affords facilities for variations in form, which may be almost said to leave the architect at perfect liberty in his design.

### *General Observations on the Physiology of Timber.*

As we cannot, in the space allotted to this article, enter into a particular examination of the nature and qualities of the different varieties of timber used in building a ship, we must confine ourselves to such observations on the physiology of timber in general, as may be of practical application.

Durability of the royal navy.

Of the mercantile navy.

Timber, when forming a component part of the structure of a ship, is subjected to many deteriorating influences that have no analogies in other combinations of wood-work. Although particular instances may be quoted of ships which have resisted decay for long periods, the average durability of the royal navy is reported not to exceed fifteen years. This we consider now an unfavourable statement; but, in the wear, tear, and neglect incidental to the constant services of war, even this average must be considerably lowered. The duration of the mercantile navy is stated at a higher average; but it must be remembered that the merchant-ship is not necessarily maintained in such perfect repair as the ship of war; and also, that the system of insurance enables both merchant and shipowner to freight and to sail ships, of which Lloyd's books record a most fearful and a most astounding tale; a tale which proves, that the longer average durability of the mercantile navy is in part purchased at a most sinful expenditure of human life; an expenditure which no amount of insurance can compensate.

Timber.

Occasional instances of durability.

The occasional instances of lengthened durability in some ships of the royal navy tend to prove, that it may be possible much to increase the average, by insuring a combination of the same causes which, perhaps accidentally in these cases, produced this effect. That this is a most important consideration is evident; for if we knew how to insure to our ships the durability recorded of the Montague, we should diminish the expense of our navy by one half; while if we could insure to them that recorded of the Royal William, we should diminish the expense to one sixth!

Classification of decay of timber.

The deterioration and decay of ships may be advantageously considered under several distinct heads. One may include the decay to which timber is subject, in common with all organized matter, and which may be either hastened or retarded, according as destructive or preservative influences prevail; another may include the variety of decay to which the name of "dry rot" has been applied; and another may include that decay which appears to be not only prematurely, but unnaturally induced, dependent on the injudicious combination of destructive agents with the inorganical compounds of the timber.

That large masses of timber in combination should be more subject to the deteriorating influences which tend to accelerate decay, is what we may be led to expect from analogy. All organization of which we have any knowledge, becomes eventually decomposed by the chemical action which takes place in its constituents. During the life and health of a plant, the various components acting under the influence of their common vitality, perform their several functions in accordance to the end of their original combination; but with the cessation of life that influence ceases, and the constituents of the organized structure assert their individual existence, and resume their original affinities. Some separate, some form new compounds, and others which the vital principle had retained in harmless combination now act energetically and destructively on each other; while the original mass, under the influence of these several causes, gradually deteriorates, and is eventually decomposed.

Decay may be accelerated or retarded.

Deteriorating influences.

Preservative influences.

This result may be accelerated or retarded by the presence or absence of those circumstances which are favourable or unfavourable to it. Temperature, moisture, the vicinity or remoteness of agents either destructive or preservative, all have great influence in promoting or retarding decomposition, principally in as far as they promote or retard the fermentative process, which appears to be the preliminary step towards the rapid decomposition of vegetable matter. A certain degree of moisture is necessary to induce this fermentation; but when the other circumstances that are favourable to the process exist, this moisture is always to be found even in the best-seasoned timber, in which, on the authority of Count Rumford, there still remains one fourth of its weight of water. This will be readily understood when it is remembered, that a very large portion of moisture is always contained in the atmosphere, to the influence of which the timber has been exposed. While moisture to a certain extent appears essential, a continued immersion, or perfect saturation, is inimical to this vegetable fermentation. Again, a moderate temperature, not so low as to induce congelation, nor so high as to cause evaporation of the moisture, appears to be favourable to it. The unavoidable dampness of the atmosphere in ships, and the difficulty of maintaining a free circulation of air, contribute much to the process of fermentation, and consequently to the destruction of the original structure of the fermenting mass, by the distribution of its several constituents, and its consequent decomposition.

The difficulty of maintaining a circulation of pure air in those portions of the vessel below the surface of the water might be removed by adapting the openings between the timbers of the frame to this purpose. Pure air might by their means be easily supplied to the lower part of the "between decks," or even to the hold, through pipes; and the foul, heated, and therefore rarefied air, would rush from the upper part of the between decks, or of the hold, through a second series of pipes. The writer of this article proposed a plan for effecting this to the Admiralty, on his return from a cruise in the experimental squadron of 1827. The same principle is adopted now, very generally, to ventilate manufactories and other large and closely-peopled buildings.

Oxygen.

Its effect.

Decay commences with the felling of the timber.

The most active agent in the work of the decomposition of timber is the oxygen which it contains, whether this decomposition be rapidly induced by fermentation, or is more slowly and gradually taking place under the influence of the law which renders decay the necessary consequence of organization. The oxygen, which, during the vitality of the plant, was held in harmless combination, is set free, and immediately begins to act upon the woody fibre of the felled timber, and induces a slow combustion, the effect of which is the evolution of carbonic acid gas, and the carbonization of the wood, by which the tenacity and adhesiveness of its several parts are gradually destroyed. Timber, therefore, begins to deteriorate and to decay from the moment of its being felled; and indeed a gradual diminution of its strength may be observed during the process of its seasoning, which only ends with its total decomposition. The hastening the seasoning process is, however, advantageous, by depriving the timber of the superabundant moisture, and of the juices, which might otherwise induce an unduly rapid decomposition.

Dry rot.

Distinctive characteristic.

Derivation of the term.

Fungi.

General causes of this decay.

The decay of timber has been frequently classed under two heads, natural decay, and decay from dry rot. Probably there is not such a marked distinction between these two decomposing principles as might be imagined. Very frequently the decomposition of timber is attended with the apparently spontaneous vegetation of parasitical fungi; and, according to common acceptation, that species of decay which is accompanied by the vegetation of these fungi has received the appellation of dry rot. The term was applied to it in consequence, probably, of the peculiarity attending it, that the decomposed wood had become a dry friable mass without fibrous tenacity. Whether the seeds of these plants are lying dormant in the juices of the timber while in a state of life and health, and the vegetative principle in them becomes active only when decomposition has furnished them a nidus, or whether they are floating in the atmosphere, and vegetate whenever favourably placed, is a point not yet established. However this may be, as in general this peculiar decay may be traced to imperfectly seasoned materials, we consider it may fairly be supposed that the seeds of the fungi are contained in a fit state for vegetation in the juices of such timber; and although it sometimes occurs and spreads among seasoned timber, it appears previously necessary that damp should have renewed and revived the vegetating principle in the seeds, and fermentation and decomposition have provided them a nidus. They then flourish and acquire strength on the sustenance which they draw from the decomposed wood; and in the same manner, and with a similar deteriorating effect as the parasitical plants which sometimes vegetate on the living tree, these destroy the dead timber, by abstracting all but the earthy particles, which are left without fibrous texture.

Preventives.

Dryness, cleanliness, a free circulation of air, or the entire exclusion of it, appear to be the best preservatives against, or checks to, vegetable decomposition; while damp accumulations, and a vitiated atmosphere, rapidly induce it.

Tendency of decay to increase.

If the foregoing statement of the principles on which the decomposition of timber depends be correct, it is evident that its tendency is progressive, and that the decay must rapidly spread, from the accumulation of the deteriorating influences. It is also evident that the only means to check undue decay is by a removal of the inciting causes; and that the only means to prevent it, is to guard against those circumstances which are most liable to induce it, and to avoid the use of those materials in which it is most easily induced.

Precautionary measures.

Unseasoned timber should never be used, and even the most seasoned timber should only be used when in a dry state. When kilning plank was first adopted, now upwards of a century ago, the planks, after being set to the form of the body, were taken off to dry; this, however, was unnecessary, kilned plank drying almost at the mouth of the kiln. All decayed and all diseased portions of the wood should be carefully removed, and also the whole of the sap or imperfect wood, which, from being more soft and spongy in texture than the spine, absorbs moisture more easily, and, being also more filled with the vegetating principle and the vegetable juices, is more liable to fermentation, and consequently to decomposition, and to the growth of the fungi.

Influence of extraneous substances.

Iron fastenings.

Cause of their destructive effect.

We shall now consider the premature decay of timber induced by the substances which are used in connection with it. Of these the iron for fastenings has by far the most injurious influence. This is probably owing to the great affinity which exists between that metal and oxygen, so that each fastening becomes an absorbent of oxygen, either from the atmosphere or from the wood which surrounds it, and which is again supplied from the atmosphere. The surface that is first subjected to this change is converted into the brown oxyde of iron, which may be termed a supersaturated oxyde, and parts with its superabundance of oxygen to the lamina of pure iron immediately beneath it, while the surface absorbs a fresh store of oxygen from the wood; and thus the process of oxidation goes on through successive laminæ of the iron, until the whole of its metallic nature is changed, and its utility as a fastening is destroyed, while it becomes a reservoir of oxygen, which acts evidently on the woody fibre around it, and, by carbonizing it, rapidly and effectually destroys its tenacity.

Constituents of oak-timber.

Of teak.

Effect of iron on teak less injurious. It therefore may be used in teak.

Action of copper on oak.

In this view of the action of iron in accelerating the decomposition of timber, we may trace the reason why its effect varies so much in different woods. Mackonochie, in his admirable Prospectus, says that oak is found to contain a much smaller proportion of oily or resinous particles than many other kinds of wood; and that, besides the lignic acid which it has in common with them, it contains an acid peculiar to itself, called the gallic acid, and that, therefore, the quantity of oxygen in oak is very considerable; that, on the contrary, in teak it is much less, while in this wood the resinous particles are so abundant as to have procured the teak-tree a place amongst the terebinthinous plants. He argues, that the iron, which cannot easily be protected before being applied as a fastening, acquires a protecting covering from the oily or resinous juices of the wood, pressed from the abraded vessels in the action of driving. This coating, which cuts off its influence on the oxygen, will be more or less perfect, in proportion to the quantities of the protecting substances contained in the wood. He states, on the authority of the experience of the shipping built in India, and used in the India trade, that the average duration of an iron-fastened teak ship is thirty years; and consequently he argues that it is a misapplication of expense to use copper fastening with teak, as the additional advantage gained is not at all commensurate with the additional expense. But with oak the circumstances are different; the action of oak on copper is not near so destructive of its metallic structure as it is on iron; and, on the other hand, the re-action of the metal on the wood is not so destructive of its ligneous fibre. The oxyde of copper, which forms almost immediately on its coming in connection with the wood, is not a supersaturated oxyde, but the portion of oxygen it has absorbed is held in strong combination; and, consequently, instead of the process of oxidation continuing from lamina to lamina, as has been described to be the case in iron, the surface oxidation becomes a natural protection of the copper from the action of the wood, and of the wood from the action of the copper, equivalent to the resinous or oily coating which supervenes in the case of iron driven into teak.

Various means of preserving timber. Mackonochie.

Use of paint.

With this view of the process of decomposition in timber, we have an insight into the *rationale* of the various means proposed for its preservation. Several writers on timber have more or less urged the foregoing principle. Mackonochie, in his Prospectus, has adopted this theory; and though his reasoning on the causes of decomposition is not given with his usual perspicuity, his deductions as to the means of preventiun are perfectly free from this objection. He recommends, that whatever iron is used for fastening, a protecting coat of paint or some other substance should be interposed between the iron and the wood, to cut off, as far as possible, the connection between the metal and the woody fibre.

Seasoning timber in the light.

Saturation with oil.

Means of effecting this.

Oil may be procured from refuse timber.

He also recommends that, in seasoning timber, care should be taken to expose it to the light, which will have great influence in making it give out its oxygen. But as it must re-absorb oxygen in the night, and will at least be supplied with it from the atmosphere, the only effectual means is at once to expel it, and fill up its space with some other substance; for which purpose, he says, "oil presents itself as the fittest, its use in defending timber from the action of the weather having been long acknowledged and practised." He recommends the following process as an easy means of impregnating the timber with this or any other similar substance. The wood is to be placed in a steam-tight chamber, and subjected to the action of steam, by which the air and gases will be expelled both from the chamber and the timber. Then, by condensing the steam, and repeating the process until the whole of the elastic fluids are withdrawn from the wood, and the non-elastic converted into vapour, the wood becomes freed from them, and if plunged into oil, and subjected to the atmospheric pressure, the whole interior of the wood will be filled with the oil. Mackonochie asserts that he then has (6th August 1803) in daily use a steam-chamber on the above principle, capable of containing from twenty to thirty planks forty feet long, or a proportionate quantity of timber, in which, while the planks are steaming to render them flexible, they are impregnated with teak oil. He says the oil may easily be procured from the chips and saw-dust used for the fuel of the steam-boilers; for it has been ascertained that Malabar teak contains such a quantity of oleaginous or terebinthinous matter, that the chips from the timber and plank of a ship built of it will yield, by a proper process, a sufficient quantity of tar for all its own purposes, including the rigging; and that although oak-timber does not contain so much of these substances, the chips of the fir consumed in the royal navy would be more than sufficient to supply tar to saturate the oak.

By M. Pallas, to mineralize it.

Mr Bill, to saturate it with asphaltum.

Mr Kyan, with corrosive sublimate.

There have been numerous proposals to impregnate timber, in a greater or less degree, with foreign substances. In 1779 a proposal was made by a M. Pallas to mineralize timber by steeping it to saturation in a solution of green vitriol, and then precipitating the green vitriol by means of lime-water. A gentleman of the name of Bill, about the year 1822, produced some samples of timber of large scantling, impregnated throughout their substance, apparently, with asphaltum. The samples thus prepared were subjected to a trial of five years' duration in the dry-rot pit at Woolwich; and we have it on the authority of Mr Knowles, the able secretary to the late committee of surveyors of the navy, that they perfectly withstood the "fungus rot," while numerous unprepared specimens were destroyed in one fifth of the above time. Sir John Barrow, whose long experience and acknowledged talent render his opinions on all naval matters extremely valuable, recommends the kreosote from the distillation of tar, which, in the shape of a gas, will, he says, penetrate every part of the largest logs, "and render the wood almost as hard as iron, so hard as not easily to be worked." Another plan, that proposed by Mr Kyan, is to soak timber in a solution of corrosive sublimate. This, on the principle advocated in this article, would be effective in all cases where the saturation was complete and permanent. Where the application is only of the nature of a surface application, there does not appear to be any reason why the corrosive sublimate should preserve the interior of the timber, or have more effect on that part than any other surface applications, excepting that it would more certainly destroy any vegetative principle which might exist in that portion near the surface to which it could penetrate.

Mr Kyan's process.

The rationale of Mr Kyan's process may be best understood by the following quotation from a lecture by Dr Birkbeck. "Aware of the established affinity of corrosive sublimate for this material (albumen), he applied that substance to solutions of vegetable matter, both acetous and saccharine, on which he was then operating, and in which albumen was a constituent, with a view to preserve them in a quiescent and incorruptible state; and obtaining a confirmation of his opinions by the fact, that during a period of three years, the acetous solution openly exposed to atmospheric air had not become putrid, nor had the saccharine decoction yielded to the vinous or acetous stages of fermentation, but were in a high state of preservation, he concluded that corrosive sublimate, by combination with albumen, was a protection against the natural changes of vegetable matter....He conceived, therefore, if albumen made a part of wood, the latter would be protected by converting that albumen into a compound of protochloride of mercury and albumen; and he proceeded to immerse pieces of wood in this solution, and obtained the same result as that which he had ascertained with regard to the vegetable decoctions." The writer of this article has seen most conclusive experiments as to the beneficial effect of "Kyanization," especially on the softer woods.

Numberless nostrums have been proposed.

Sir William Burnett.

Innumerable nostrums have been recommended as surface applications for preventing the decay of timber. Knowles, in his work on the Preservation of the Navy, gives a list of twenty-nine, besides many others the components of which were kept secret by their projectors. There does not appear to be sufficient evidence to prove the decided advantage of any of these applications; on the contrary, unless the timber to which they are applied should be thoroughly seasoned, all coatings on it which prevent the progress of the seasoning process, and confine the vegetable juices, have been proved to be injurious. If timber be already well seasoned, the principal preventives to decay appear to be ventilation and the exclusion of damp; and with unseasoned timber the same means will accelerate the process of seasoning. Those means of preventing decay by saturation with some chemical agent, and thus altering the nature of the timber by a chemical action on its constituents, appear to be the most likely to produce decided results. The physician-general of the navy, Sir William Burnett, finding that the precipitate caused by the kyanization was soluble in salt water, has lately substituted for that process saturation with the chloride of zinc; the precipitate which this forms with the albumen being unaffected by the action of the salt water. The beneficial effect of this chloride is very decided, in those specimens which the writer has had an opportunity of examining.

Time for felling timber.

There has been much controversy as to the proper season for felling timber, into which we cannot devote space to enter. The argument appears to be in favour of the greater durability of winter-felled timber. In fact, the controversy appears more to have arisen from a desire to provo that spring-felled timber was not unequal to winter-felled, than for the purpose of eliciting truth; the bark being more easily detached and more valuable from off a spring-felled than from off a winter-felled tree.

## *Laying Off.*

*General observations and definitions.*—Laying off is delineating the form of a ship according to its actual dimensions, in order to supply the workmen with the exact shape and proper positions of the principal pieces of timber which compose the structure. If the floor be sufficiently spacious, the ship may be laid off in one length; if otherwise, the operation must be performed in two or more lengths, according to circumstances.

The principal plans of a ship are the sheer, body, and half-breadth plans.

**Sheer plan.** *1st*, The sheer plan is a projection on a vertical longitodinal plane, dividing a ship into two equal parts. Plate CCCCL. fig. 24.

**Body plan.** *2d*, The body plan is a projection, on an athwartship plane, of transverse vertical sections of the ship, which sections are square to the keel. Fig. 25.

**Half-breadth plan.** *3d*, The half-breadth plan is a projection, on a horizontal plane, of various sections of the ship. Fig. 26.

The principal lines employed, as well in the construction of a draught, as in laying off a ship, are water-lines, level lines, diagonal lines, and buttock and bow lines.

**Water-lines.** *1st*, Water-lines, in the sheer plan, are straight lines drawn parallel to the surface of the water. In the half-breadth plan, the water-lines show the boundaries of the sections of the ship, at the corresponding heights in the sheer and body plans. Figs. 24, 25, 26.

**Level lines.** *2d*, Level lines are similar to water-lines, except that they are drawn parallel to the keel instead of to the water. To avoid confusion, the level lines are omitted in the sheer draught, but they are drawn in Plates CCCCLI. and CCCCLII.

**Diagonal lines.** *3d*, Diagonal lines show the boundaries of various sections formed by planes which are oblique to the vertical longitudinal plane, and which intersect that plane in straight lines parallel to the keel. Plate CCCCL. figs. 25 and 26.

**Buttock and bow lines.** *4th*, Buttock and bow lines are the boundaries of vertical sections of the ship, parallel to the vertical longitudinal plane. See B. L., figs. 24, 25, 26.

**Main-breadth line.** The main-breadth line is the boundary of the widest part of the ship in each of the three plans. Plate CCCCL.

**Top-breadth and top-side lines.** The top-breadth or top-timber line, in the sheer plan, is a line drawn to the sheer of the ship, fore and aft, at the height of the under side of the gunwale amidships; and the top-side line is a sheer line drawn above the top-timber line, at the extreme height of the side of the ship. Plate CCCCL.

**Cutting-down line.** The cutting-down line is a curve in the sheer plan which corresponds to the upper surface of the throats of the floors amidships, and to the under side of the keelson. Plate CCCCL.

**Fore and after bodies.** Fore and after bodies. These combined constitute the whole of the ship. They are supposed to be separated by an imaginary athwartship section, at the widest part of the ship, called the midship section, or dead-flat.

**Midship body.** Midship body, as sometimes used, applies to an indefinite length of the middle part of the length of a ship, incloding a portion of tho fore and after bodies.

**Square and cant bodies.** Square and cant bodies may be considered as subdivisions of the fore and after bodies. There is a square fore-body, a square after-body, a cant fore-body, and a cant after-body. In the square body the sides of the timbers are athwartship vertical planes, whereas in the cant body the sides of the timbers, although vertical, are not athwartship planes.

**Moulding and siding.** Moulding and Siding. These terms are nearly synonymous with thickness and breadth; observing that the moulding of a piece is the dimension of the side on which the mould is applied for determining its shape or curvature. For instance, the moulding of a beam is its depth or thickness; its sidiog is its fore and aft dimension, or breadth.

**Room and space.** Room and space is a certain distance determioed by the siding of two adjacent timbers, together with the openings between them; or it is the distance apart of the joints of the frame, as from A to B in the disposition of the timbers, or one half the distance apart of tho stations B, D, F, &c. in the sheer plan. Plate CCCCL. fig. 24.

**Shift.** Shift. This, in its general sense, refers to a certain arrangement among the component parts of a ship. Thus we speak of a shift of plank, a shift of dead-wood, meaning thereby the disposition of the buts of the timber or plank, both with respect to strength and economy. In a more limited sense, "shift" means the distance apart of two neigbbouring buts or scarphs.

**Bevellings.** The bevelling of a timber is the anglo contained between two of its adjacent sides. Bevellings aro either acute angles, right angles, or obtuse angles. These three separate cases are denominated under bevellings, square, and standing bevellings.

**Sirmarks.** Sirmarks are certain stations marked on the moulds of the timbers at which the bevellings are applied. These sirmarks are denoted in the body plan by the various diagonals.

*Description of the draught, consisting of the sheer, body, and half-breadth plans.*—The principal dimensions of a ship are length, breadth, and depth. Connected with and dependent on these three dimensions, are three plans, named the sheer, half-breadth, and body plans. These combined constitute what is termed the draught of a ship. We purpose to describe them separately. Plate CCCCL.

**Sheer plan.** *1st*, The sheer plan or elevation (fig. 24) is the representation of an imaginary longitudinal section, dividing the ship into two equal parts, by a vertical plane passing through the middle of the keel, stem, and stern-post. This section is bounded by the fore part of the knee of the head, under side of the keel or false keel, aft side of the rudder, rake of the stern, and the sheer of the upper part of the top-side.

Besides this plan being a section of the ship amidships, showing tho sheer of the decks, cutting-down line, stations of the masts, &c., on it are also projected, in lines perpendicular to the aforesaid longitudinal section, the ports, cat-head, head-rails, side counter-timber, quarter-gallery, main-breadth line, channels, dead-eyes, &c. From all this we see that the chief use of the sheer plan is to obtain heights and lengths; heights measured from the upper edge of the rabbet of the keel, and lengths measured from the after or tho fore perpendicular. **Perpendiculars.** These perpendiculars, which define the length of the ship, are drawn in most ships of war at the ends of the lower or gun deck; the foremost perpendicular at the aft side of tho rabbet of the stem, the aftermost at the foreside of the rabbet of the stern-post.

Occasionally the interior fittings and accommodations are shown on the sheer plan, as the beams, magazines, store-rooms, well, pumps, capstans, cabins, and other minutiæ; bot as these produce confusion by multiplying lines, it is usual to represent the interior economy of the ship on a separate plan, called the "profile," or plan of the inboard works. **Profile.**

**Half-breadth plan.** *2d*, The half-breadth plan (fig. 26) principally shows the form of the ship, *1st*, when cut by water-lines; *2d*, by level lines; and, *3d*, by diagonal lines. As before observed, the planes of these diagonal sections intersect the longitudinal plane of the ship, in straight lines parallel to the keel. Besides the above, the form of the decks, main-breadth and top-breadth lines, may be also delineated on the half-breadth plan; together with the projection of the planes of

Laying Off.

the fore and after cant timbers, which will be more particularly explained in the sequel.

Body plan.

3*d*, The body plan (fig. 25) is simply a representation of vertical transverse sections, before, at, and abaft the widest transverse section, which is termed "dead flat," and usually denoted by the symbol ⊕.

The sections in the body plan in the fore-body are distinguished by letters, A, B, C, &c., those in the after-body by figures, 1, 2, 3, &c., corresponding with the same letters and figures in the sheer and half-breadth plans. It must be understood, that the sections in the body on the right of the middle line represent the starboard fore-body, whilst those on the left of the middle line represent the larboard after-body, of the ship.

It is thus seen, that from the aforesaid three plans we may derive correct ideas of the form of a ship, which form is obtained

| | |
|---|---|
| From the sheer plan, | by vertical fore and aft sections parallel to the vertical longitudinal plane, as seen by the buttock and bow lines; |
| From the body plan, | by athwartship vertical sections, square to the keel, and at right angles to the vertical longitudinal plane; |
| From the half-breadth plan, | 1*st*, by water-lines, or by planes parallel to the water; 2*d*, by level lines, or by planes parallel to the keel; 3*d*, by diagonal lines, or by planes inclined at any angle to the horizon. |

The reader will also perceive from the preceding remarks, that

| | | |
|---|---|---|
| The sheer plan | is a projection | on a vertical longitudinal plane; |
| The body plan | | on a vertical athwartship plane; |
| The half-breadth plan | | on a horizontal plane. |

As before remarked, the three above-described plans constitute the draught of a ship. We shall presently see their mutual dependence on each other, so that any two being given, the third may be obtained.

Profile.

Disposition.

Midship section.

Scheme of scantlings.

Besides the sheer draught, it is customary to furnish the architect with a profile of the inboard works before explained; the "disposition," or the appearance of the timbers which constitute the frame, showing the heads and heels, and general arrangement of the futtocks; the midship section, on which is described the moulding, or athwartship size of the timbers, the thickness of the exterior and interior planking, the connection of the beams to the side, the dimensions of the water-ways, shelf-pieces, the description and fastening of the knees, &c. These, together with a scheme of scantlings, which is a document containing the dimensions, and other particulars, of the principal pieces which enter into the construction of the fabric, constitute all the preparatory information required by the builder.

After these general observations, we shall now enter more in detail into the description of the draught of a ship; but as laying off and practical building are so intimately connected, that a perfect knowledge of the one cannot be attained without some acquaintance with the other, it becomes previously necessary to describe, in general terms, the method in which the timbers of a ship are combined and disposed, both in the square and cant bodies.

This constitutes another division of our subject.

Frame of a ship.

The timbers of a ship are combined together in assemblages which are technically called "frames;" these are put together in a certain predetermined order, depending on a variety of circumstances, as the size and form of the ship to be built, the nature and dimensions of the timber to be used, the skill and judgment of the architect employed. We will suppose each frame to consist of a floor crossing the dead-wood, a first futtock stepping against the dead-wood, a second futtock on the head of the floor, a third futtock on the head of the first futtock, a fourth futtock on the head of the second futtock, and, lastly, a top-timber on the head of the third futtock. The above arrangement accords with the old system of building.

Old system.

Short-timber frame.

An economical modification of the plan was introduced of late years, by diminishing the length, and therefore by increasing the number, of the timbers. Thus the long floors are abolished, and their place is substituted by shorter floors, called cross timbers. To the sides of these cross timbers, giving scarph to and projecting beyond them, are bolted and dowelled pieces, called half floors. The first futtock will then but on the head of the cross timber, the second futtock on the head of the half floor, the third futtock on the head of the first, the fourth on the head of the second, the fifth on the head of the third, the sixth on the head of the fourth, and the top-timber on the head of the fifth. Occasionally lengthening pieces are added to the upper timbers, when required by the conversion. See figs. 34, 35, 36.

Figure 49, Plate CCCCLVII., represents a disposition with the buts of the frame arranged like those of a shift of plank, there being three timbers between every two buts, while in the usual disposition there is only one timber between every two buts.

Joints.

By reference to the disposition of the frame, Plate CCCCLIV., it is seen that the timbers are not in contact sideways, but are kept apart a certain distance; although, for the sake of simplicity in laying off, we suppose them to touch each other from the keel to the top-side. This imaginary junction of the futtocks of a frame is called the joint. The joints of the frames are, with one exception, equidistant. This exception is seen in fig. 24, Plate CCCCL., in which the distance between the joints 3 and (2) is greater than between the other joints. This variation is for the purpose of introducing an additional timber, called the "single timber," so that there will be five timbers in the space 3 (2), whereas there are only four timbers between the other joints. Hence the opening in question is called the five-fourth opening; and one frame, instead of consisting, like all the others, of two adjacent timbers, will consist of an assemblage of three timbers. The reason of the introduction of the single timber is, because the position of the various futtocks is reversed in the fore and after bodies, *i. e.* those which in the fore-body are on the fore side of the joint, are placed in the after-body on the aft side of the joint. Hence, were it not for the single timber breaking the shift of the heads and heels, we should have a series of two buts together, as two first-futtock heads, and so on. The timbers being square to the keel, the joints will obviously be represented in the sheer and half-breadth plans by straight lines square to the keel.

Single timber.

Square body.

As before explained, these joints and their corresponding frames are distinguished in the fore-body by letters, as A, B, C, D, &c. and in the after-body by figures, as 1, 2, 3, 4, &c. Thus it is seen that the sides of the timbers already described are athwartship vertical planes. This arrangement, however, is departed from at the two extremities of the ship; for if the sides of the frames were athwartship, timber of much larger scantling would be required, which would be more costly, more liable to decay from converting older trees, and would be still farther objectionable, from the fastenings, which ought to be square to the curve, cutting the timbers more obliquely. To obviate these inconveniences, the timbers, in technical language, are "canted."

Cant body.

Square and cant bodies.

It has been before explained, that the sides of square timbers are vertical planes; so also are those of cant timbers. Again, the intersection of the plane of the square timber with the vertical longitudinal plane of the ship, is a vertical straight line: the same remark is applicable to the cant-timber. Further, the plane of the square timber is at right angles to this longitudinal plane, whereas that of the cant timber is oblique to this plane. The subject of square and cant timbers has been explained by the following familiar illustration. Imagine the before-named vertical athwartship plane to be fixed at its intersection with the vertical longitudinal plane, but still allowed to revolve on the vertical line of intersection as an axis. It may be considered as a door on its hinges. When the door is wide open, in other words, when the plane stands athwartships, it represents a square timber; when the door is partially closed, or allowed to revolve on its hinges, it represents a cant timber. This imaginary revolution, of course, takes place forward in the fore-body and aft in the after-body. Thus, in the half-breadth plan, Plate CCCCL., AB, drawn perpendicular to the middle line of the ship, represents the joint of a square frame; but if it is made to revolve forward round the point A, till it comes into the position A*b*, it then represents the joint of a cant frame.

The draught of a ship.

Keel.

Perpendiculars.

Stem and stern-post.

Load water-line.

We have now to explain the manner of drawing the various lines and sections of a ship, and of transferring them from one plan to another. For this purpose it will be convenient to imagine the draught complete, and in a general way to retrace the steps by which the completion was effected, by explaining the adaptation and correspondence of the three plans with each other. Below the upper edge of the rabbet of the keel are drawn the depth of the rabbet and the under sides of the main and false keels. At a distance apart, equal to the length of the ship, are drawn the foremost and aftermost perpendiculars, at right angles to the keel, and respectively intersecting the aft part of the rabbet of the stem, and the fore part of the rabbet of the stern-post, at the height of the lower deck. The stem and stern-post, together with their respective rabbets, are likewise delineated. From the calculation of the weight of the ship when fully equipped, as already explained, is determined the position of the upper or load water-line; the other water-lines are drawn at pleasure parallel to, and generally equidistant from, the load water-line. They are severally marked No. 1, 2, 3, 4, &c. (Plate CCCCL.), observing that they are characterized by the same figures in the body and half-breadth as in the sheer plan.

Sheer of the decks.

The load water-line being drawn in the sheer draught, the height of the lower deck may be determined. It is to be observed, that a deck is delineated by three lines, the upper two of which are parallel to each other, and represent the thickness of the deck at the middle; the third or lower line denotes the under surface of the deck at the side of the ship. Supposing the height of the deck determined amidships, forward and aft; let these heights be set above the load water-line, and through the three spots thus obtained draw a segment of a circle; this curve defines the deck at the middle. To obtain the deck at the side, proceed as follows. Draw a straight line, equal in length to the breadth of the ship amidships, to the interior of the timbers. Perpendicular to and at the middle of this line, set off the round-up of the beam, through which point and the extremities of the line draw the segment of a circle, which will represent the round-up of all the beams. Draw a tangent to this curve at its middle point, which will evidently be parallel to the first-named line, or chord of the arc. Now, to obtain the round-down of the deck at any particular station, take the half-breadth of the ship at that station, and set off this half-breadth on the tangent from the middle of the curve. Next take the perpendicular distance (at right angles to the tangent) of the curve from the point last obtained, and set it off on the sheer plan at the corresponding station below the under side of the deck at the middle; the spot thus obtained is the deck at the side. By proceeding in a similar manner at other stations we obtain several spots through which a fair curve must be drawn, and thus is determined the under surface of the deck, or the upper surface of the beam at the side of the ship. In like manner are the other decks delineated, their height and round-up being known. At present, however, only the lower deck can be decided. Before the upper deck, quarter-deck and forecastle, and round-house, are drawn, it will be necessary to draw, in the sheer draught, the midship and side counter-timbers. We here remind the reader that we are alluding to a two-decked ship, whereas the sheer draught (Plate CCCCL.) represents a frigate, which has one fighting deck less than a line-of-battle ship.

Wing-transom.

As the heels of the stern or counter-timbers rest on and are connected to the wing-transom, this transom may be considered as the foundation of the stern. To draw the wing-transom, set up in the sheer plan, from the upper edge of the rabbet of the keel, the height of its intersection at the middle line of the ship with the fore part of the rabbet of the stern-post. At this point draw a horizontal line, below which draw a second horizontal line, at a distance from the former equal to the round-down of the transom. On the upper horizontal line set off the round-forward of the transom, which square down to the second horizontal line. Next join the last-named point and the point of intersection of the upper surface of the transom, with the fore part of the rabbet, and we thus obtain the after upper edge of the transom. It is to be understood that the method just described for drawing the wing-transom is only an approximation to truth: thus we have supposed the after upper edge of the transom a straight line, whereas in reality its projection is a curve; but as this description is sufficiently accurate for our present purpose, we shall reserve any further remarks on the subject until we explain the method of laying off the transoms.

Having drawn a line to represent the after upper edge of the wing-transom, the fore and after extremities of this line will be respectively the terminations of the after parts of the lower ends of the midship and side counter-timbers; but before these timbers are described, it will be necessary to make a few observations on the stern of a ship.

The stern.

If we imagine the stern to be cut by a vertical fore and aft plane, the after boundary of this section, above the wing-transom, will consist of the hollows of the lower and upper counters, and a straight line from the upper knuckle to the top of the side. Moreover, the stern has two curvatures, a round-up and a round-aft. The round-up is variable, whereas the round-aft (above the upper knuckle) is constant. The round-up of the stern gradually increases from the wing-transom to the taffrail; that is, the right aft rails, which include the tuck-rail, the lower counter, upper counter, foot-space, and breast-rails, have more and more curvature as they ascend. The round-aft of the stern, from the upper knuckle to the taffrail, is the same in equal breadths; in fact, the stern is a portion of a cylinder, and therefore all sections square to its axis, or square to the rake, which is parallel to its axis, are portions of the same circle.

Counter-timbers.

We may now proceed to draw in the midship counter-timber. The stations of the upper and lower knuckles being determined, draw a circular arc to the hollow of the upper counter; and from the lower knuckle to the intersection of the upper edge of the wing-transom with the fore part of the rabbet of the stern-post draw another curve to the hollow of the lower counter. From the upper knuckle draw a straight line to the rake of the stern, and we thus complete the projection of the midship counter-timber.

Side counter-timber.

To draw in the side counter-timber in the sheer plan. At the height of the upper knuckle of the midship counter-timber draw a horizontal line; at the distance of the round-down of the upper counter below this line draw another horizontal line, on which set off the round-forward of the upper counter square to the rake. The point thus obtained will be the upper knuckle at the side. In like manner is obtained the lower knuckle at the side. From the two knuckles draw in the hollow of the upper counter, and from the lower knuckle to the fore part of the after edge of the wing-transom draw in a curve for the hollow of the lower counter.

Now if the top-side had no "tumbling home," the side counter-timber above the upper knuckle would be parallel to the midship counter-timber; and further, in proportion as the "tumbling home" is great or small, so will the heads of these timbers approximate to or recede from each other.

To obtain a point for the head of the side counter-timber, it will be first necessary to draw the round-aft of the stern. Strike a straight line at pleasure, the length of which is equal to the breadth of the stern at the lower knuckle. At the middle of this line erect a perpendicular, and on it set off the round-aft of the stern; through this last point, and the extremities of the line, draw a circular arc, from which we may obtain the round-aft of the stern, square to its rake, at any breadth. For instance, to procure the round-aft at the head of the side counter-timber, set off the half breadth of the ship at that height from the middle of the chord of the arc; then take the distance of this point (square to the chord) from the circular arc; this distance is the round-aft required, which, when set off square to the midship counter-timber, determines the aft side of the side counter-timber at its head. We have now to obtain spots for drawing in this timber between the head and the upper knuckle.

**Stern.** As before remarked, the stern above the upper knuckle is cylindrical, and as all sections of a cylinder parallel to its axis are bounded by straight lines, while those sections which are oblique to its axis are bounded by curves, it follows, that in the sheer plan the midship counter-timber, as explained above, is a straight line, while the side counter-timber is a curve.

Further, as all sections of a cylinder made by a plane square to its axis are circles, while those sections which are oblique to its axis are ellipses, it follows, that in the half-breadth plan the round-aft of a plane, which in the sheer plan is at right angles to the rake of the stern amidships, will be circular, while the round-aft in the half-breadth plan of all other planes will be elliptical.

**Round-aft.** Bearing this in mind, we proceed to show the manner of obtaining the elliptical round-aft of the level line Q at the height of the upper knuckle o at the sides (Plate CCCCLIII. fig. 31). In the sheer plan, from the point *a* draw *ob* at right angles to the midship counter-timber produced. Project the point *a* in the sheer plan to the middle line of the half-breadth plan, as *e*. From *e* draw *ef* at right angles to the middle line, and on *ef* set off the half breadth of the ship at the lower knuckle. Draw *eg* equal to *ab*, and through *g* and *f* draw a circular arc *ghf*, the radius of which arc will be equal to half the diameter of the cylinder; then will *ghf* be the round-aft of the stern square to its rake. Again, in the half-breadth plan draw any number of lines W, X, parallel to the middle line, intersecting the round-aft *ghf* in the points *h* and *i*. Take the horizontal distances of *h* and *i* from *ef*, and set these distances off on the line *ab* from the point *a*. Through the points thus obtained on *ab* in the sheer plan, draw lines parallel to the rake of the stern. Square down the points of intersection of the last-named lines, with the level line Q, to the corresponding lines W and X in the half-breadth plan. Lastly, through the intersections thus obtained draw a curve, which will represent the elliptical round-aft of the stern when cut horizontally. Further, as all parallel sections of a cylinder are similar curves, we infer that the round-aft just obtained will serve for the round-aft of any number of level lines drawn above the upper knuckle.

Therefore draw level lines above the upper knuckle, at a distance of from two to three feet apart, both in the sheer and body plans. Run off these level lines in the half-breadth plan. Square down the intersections of each of these lines in the sheer plan, with the midship counter-timber, to the middle line of the half-breadth plan. From these points draw the horizontal round-aft of the stern, and the intersections of this round-aft with the corresponding level lines will be the terminations of the said level lines. Square up these terminations to the respective level lines in the sheer plan, and through these spots draw a curve, which will be the projection of the after edge of the side counter-timber.

**Side counter-timbers.** To represent the projection of the side counter-timber in the body plan, take the distances square from the middle line in the half-breadth plan of the termination of each level line, and transfer these distances to the corresponding level lines in the body plan; through the spots so obtained pass a curve, which will represent the required projection of the side counter-timber. (Plate CCCCLIII. fig. 33.)

**Decks.** Following the previous directions, the decks above the lower deck may now be drawn.

**Ports.**

The joints of the frames are drawn perpendicular to the keel. The previous explanation on the frame-timbers of a ship renders any further remarks on this subject unnecessary. The ports are drawn to the sheer of the ship. Their number, size, and distance apart, of course, depend on the determined armament.

**Breadth-lines.** The main-breadth, top-breadth, top-side, and other lines, have been already explained; and with respect to the channels, head-rails, and other details, our limits preclude the possibility of entering into a description. We must therefore conclude our account at present of the sheer plan by referring to Plate CCCCL., and proceed to a brief description of the body plan. Fig. 25 represents the body plan. A horizontal line is drawn for the upper edge of the keel. On this line three perpendiculars are raised, at a distance apart equal to half the moulded breadth of the ship. The middle of these three lines represents the middle line of the ship, or rather the projection of the vertical longitudinal plane which divides the ship into two equal parts. The other two lines are the boundaries of the ship at the widest part, or dead-flat, ⊕. The curves A, B, C, &c. in the fore-body, and 1, 2, 3, &c. in the after-body, represent vertical transverse sections of the ship, at the corresponding joints A, B, C, &c. 1, 2, 3, &c. in the sheer plan. It is to be understood that these sections correspond to the exterior surface of the timbers, on the supposition that the plank of the bottom and top-side is not yet on the ship.

**Body plan.**

**Buttock lines.**

**Diagonals.**

**Ribbands and harpins.**

Independent of the joints of the frame, many other lines in the body plan originate in the sheer plan, as port-sill lines, top-breadth, top-side, water-lines, &c. We shall presently describe the manner of transferring them from the sheer to the body plan. But there are other lines which may be said to originate in the body plan. Among this class may be mentioned buttock, bow, and diagonal lines. Buttock lines are vertical lines drawn at discretion at any distance from and parallel to the middle line. They are marked Nos. 1, 2, 3, &c. Plate CCCCLII. The position of the diagonal lines drawn in the body plan is not, however, arbitrary, because it has reference to two considerations, the length of the timbers, and the station of the ribbands and harpins: thus those marked floor-head, first futtock-head, second futtock-head, &c. show the lengths of the floors and futtocks, together with the heights of their heads and heels above the keel; while those marked first sirmark, second sirmark, third sirmark, &c. show the heights and situations of the various harpins and ribbands, which are placed between the heads of the respective timbers, in order to give support to the ship whilst in frame. Fig. 30.

**Half-breadth plan.** The half-breadth plan is in most draughts placed below the sheer plan, the stations being squared down to its middle line. (Plate CCCCL.). Occasionally, however, the upper edge of the keel in the sheer plan answers to the middle line of the half-breadth plan, as in Plates CCCCLI., CCCCLII., and CCCCLIII. This is generally the case in laying off, because the dimensions of the mould-loft floor would not admit of any other arrangement.

From the description of the draught we proceed to explain the manner of transferring the various lines from one plan to another.

Diagonals.

To run off the diagonals in the half-breadth plan. From the point of intersection of the diagonal with the middle line in the body plan, take the distances of the intersection of every timber with the said diagonal, which distances set off on the corresponding timbers in the half-breadth plan. Through the points thus obtained pass a curve, which will represent a vertical projection of the diagonal on the half-breadth plan, not in its original position, but after it is supposed to revolve until it comes into a horizontal position. The axis of revolution is a fore and aft line parallel to the keel, being the intersection of the diagonal plane with the vertical longitudinal plane of the ship. It remains to explain the method of ending the diagonals; but before the process can be clearly understood, it will be necessary to enter into a brief explanation of the rabbets of the stem and stern-post.

Rabbets of the stem, &c.

The upper part of the rabbet of the stem, and also of the stern-post, is an equilateral triangle, whose sides are equal to the thickness of the bottom plank, the middle of the rabbet being half the distance between the fore and after edges. But at the lower part of the stem, although the fore part of the rabbet remains fixed, yet the middle and the after edges vary considerably from their relative positions at the upper part.

This variation is technically termed the "opening of the rabbet," and it arises from the alteration of the form of the body. Thus, if we conceive the bow to be of the same shape above and below, no alteration would be required in the form of the rabbet. Again, if the bow were so sharp near the keel that its horizontal section becomes a fore and aft straight line, then the ends of the bottom plank should be cut off square, and therefore in the sheer plan the middle of the rabbet would coincide with the fore edge. Hence we see that the middle of the rabbet approximates to or recedes from the fore edge, according to the sharpness or fulness of the lower part of the bow. In general, it will be sufficiently accurate for all practical purposes to place the middle of the rabbet at the lower part one third its breadth from the fore edge, from which point it gradually recedes from the fore edge till it arrives at the upper end of the stem, where, as before observed, it is midway between the fore and after edges.

The same remarks obviously apply to the rabbets of the stern-post and keel; observing, that with respect to the keel, the rabbet amidships is an equilateral triangle, the middle of which is equidistant between its upper and lower edges, whereas forward and abaft, the projection of the middle of the rabbet of the keel, in the sheer plan, with respect to the lower edge of the rabbet, partakes of a similar variation, as before described with respect to the rabbet of the stem. In general it should be understood, that that form of rabbet is to be adopted which most conduces to its utility as a security of the wooden ends, and the efficiency of their caulking, so that there shall be no tendency to set off the buts of the plank.

Ending the diagonals.

For determining the endings of the diagonals, it is further necessary to observe, that the half siding of the stem and stern-post must be drawn in the body plan, together with the depths of their respective rabbets; observing, that with respect to the stem, it is usual to make it of a parallel siding from the head to the lower side of the lower cheek, in order to afford greater support to the bowsprit and knee of the head. From the lower cheek downwards it gradually tapers to the siding of the keel. The stern-post either tapers the whole of its length, or is of a parallel siding from the head to the lower side of the deck-transom, from whence it tapers to the heel. From our preceding remarks, it will be perceived, that in the half-breadth plan the upper diagonals will terminate at the aft part of the rabbet of the stem, and the lower diagonals at the middle of the rabbet. Hence there will be an intermediate point depending on the comparative fulness and sharpness of the bow, at which one diagonal will terminate both at the middle and at the after part of the rabbet; or rather this one diagonal will break in fair with both the middle and after part of the rabbet.

To determine the endings, we proceed thus: In the body plan take the heights of the intersections of the diagonal with the outside of the stem, and with the inside of the rabbet; transfer these heights to the sheer plan, to the after side and to the inside of the rabbet; square down these two spots to the middle line of the half-breadth plan, at which points raise two perpendiculars; along the diagonal in the body plan take the distances from the middle line to where the diagonal intersects the inside of the rabbet and outside of the stem, and set these distances off on the corresponding perpendiculars in the half-breadth plan; thus will be obtained two points, one of which will be the termination of the diagonal according to the form of the body, as before explained.

Or, in the half-breadth plan, with the fore part of the rabbet as a centre, and the after part of the rabbet as a radius, describe a portion of a circle, and let the diagonal at its termination be a tangent to this circle. The after ends of those diagonals which are below the wing transom terminate in the rabbet of the stern-post, in a similar manner to the fore ends in the rabbet of the stem.

The termination of those diagonals which cross the wing-transom is thus explained. In the body plan, take the distance square to the middle line of the intersection of the diagonal with the margin. Set this distance off in the half-breadth plan, square to the middle line, to intersect the margin. Through the spots thus obtained draw a perpendicular to the middle line, on which perpendicular set off the diagonal distance of the intersection of the diagonal with the margin in the body plan. This gives the termination required.

Water and level lines.

The foregoing remarks will serve to elucidate the plan of terminating water-lines, and also all level lines which are below the wing-transom; excepting that the distances in the latter cases are taken horizontally instead of diagonally.

To run off diagonals in the sheer plan.

To run off the diagonals in the sheer plan: In the body plan, take the perpendicular heights, that is, the heights square to the upper edge of the keel, of the intersection of the diagonal with each of the timbers, and transfer these heights to the corresponding timbers in the sheer plan. Through the points thus obtained draw a curve, which will be the line required.

These lines terminate forward at the aft side of the rabbet of the stem, and aft at the fore side of the rabbet of the post, at the respective heights of their intersection in the body plan, with the sides of the stem and stern-post.

These lines are chiefly required in the sheer plan, when making a disposition of the timbers of the frame; as by their means we show the heights above the keel, of the floor-heads, first futtock-heads, &c.

The horizontal ribbands in the half-breadth plan.

To run off the horizontal ribbands in the half-breadth plan. Having run off the diagonal planes, as just explained, in their true form, it will be necessary to obtain their vertical projections in the half-breadth plan, without imagining them, as before, to revolve into a horizontal position. The diagonals, when projected according to this second method, are called "horizontal ribbands."

Observe the points of intersection of the diagonal in the body plan with each timber. Take the horizontal distance of each of these points from the middle line, and transfer it on the corresponding timber in the half-breadth plan. Through the points thus obtained draw a curve which will terminate both forward and abaft on the same lines as the corresponding diagonal, only observing that the distances of the terminations must be taken in the body plan horizontally instead of diagonally.

Water and level lines in the half-breadth plan.

To run off level lines and water lines in the half-breadth plan. Take the horizontal distances, from the middle line of the ship, of the intersection of each timber with the level or water line in the body plan, and set off these distances from the middle line of the half-breadth plan on the corresponding timbers. Through the points thus obtained pass a curve.

The terminations of these lines below the wing-transom have been already explained.

To terminate the after end of a level line above the wing-transom. From the sheer plan square down the intersections of the level line with the aft part of the midship and side counter-timbers, to the middle line of the half-breadth plan. From the foremost of the two points thus obtained, erect a perpendicular to the middle line, and the point where the round-aft of the stern drawn from the aftermost point intersects the perpendicular, will be the termination of the level line.

Without further explanation, this method will serve for the terminations of the top-breadth, top-side, port-sill, and other similar lines. The fore ends of these lines may terminate in the half-breadth of the stem from the middle line.

Buttock and bow lines in the sheer plan.

To run off buttock and bow lines in the sheer plan. In the body and half-breadth plans, buttock and bow lines are straight lines parallel to the middle line. To transfer them from the body to the sheer plan, proceed thus: in the body plan, from the upper edge of the keel, take the heights of their intersections with each timber, and set off these heights on the corresponding timbers in the sheer plan. Through the spots thus obtained pass a curve. Those lines which do not cross the wing-transom may terminate in the sheer plan, at the main-breadth line. Those which cross the wing-transom terminate at the margin as follows. Square up the intersection of the buttock-line with the margin of the wing-transom in the half-breadth plan, to the margin in the sheer plan. The spot thus obtained determines the ending of the buttock-line.

Main-breadth line.

To run off the main-breadth line in the sheer and half-breadth plans. In the body plan this line is a curve passing through each timber, at its widest part. It is transferred to the sheer plan by levelling in its intersection with each timber, to the corresponding timbers; and it is drawn in the half-breadth plan in a manner similar to that before described with respect to water-lines.

We now suppose the draught is complete, and that due precautions have been taken to make the various curves in the three plans perfectly fair. We proceed to explain the method of laying off the more important parts of a ship.

Transferring to the floor.

It will be unnecessary to allude to the manner of transferring the sheer and body plans from the paper on which they are first drawn to a small scale, to the mould-loft, on which they are to be delineated the full size of the ship. The process will be sufficiently obvious to any intelligent person. We will therefore suppose the sheer and body plans transferred to the floor of the mould-loft. This being done, the next operation is to fair the body, by horizontal, vertical, and oblique sections, which is effected by running off in the half-breadth plan, according to our previous description, level lines, buttock-lines, and diagonal lines.

Fairing the body.

Proof timbers.

It should be understood, that, forward and aft, it is necessary to run off a few vertical sections nearer together than the other sections. This is done on account of the sudden curvature in the bow and buttock of a ship. These sections, which are called "proof timbers," may be placed according to discretion; observing, however, that it is essential to have one near the end of the wing-transom.

Joints of the frames.

When the body is perfectly fair on the floor, it becomes necessary to get in all the alternate timbers, or rather joints of the frames, which have been omitted. In the half-breadth plan, bisect the spaces between every joint already laid off, and strike in the new joints, which, like the others, will be square to the middle line. Then in the half-breadth plan take the distances from the middle line, of the intersections of these joints with each of the level lines and diagonals, and transfer these distances to the corresponding level lines and diagonals in the body plan. Thus will be obtained a series of spots through which curves must be drawn to represent the new joints, when all the moulding edges in the body plan will be complete.

Moulds.

Supposing the body plan complete, the moulds may be made for the timbers in the square body. With respect to the floors, it is customary for one large mould to contain them all, the fore and after bodies being placed on its opposite sides. This mould, for lightness and convenience, is made of battens; it is connected at the middle line by a pair of hinges, so that when not in use it may be shut together, and thus occupy only one half the space. In trimming a floor, after the spots are obtained from the mould for its curvature, it is sometimes customary to apply the adjacent first futtock-mould through them. With respect to the futtocks, for the sake of illustration, let us imagine one frame of the ship (as starboard, K), instead of consisting of a floor, first futtock, second futtock, third futtock, fourth futtock, and top-timber, to consist simply of two long timbers, each extending from the dead-wood to the top of the side, one on either side of the joint. Were we to make a mould to K in the body plan, it is obvious that it would give the form of both these imaginary long timbers. The only difference in the application of the mould would be, that in moulding the foremost of these timbers the after side of the mould would be uppermost, whereas in moulding the after timber, the fore side of the mould would be uppermost. The reverse would obviously be the case in moulding the larboard timbers. Now, bearing this principle in mind, the moulds are made for the various futtocks, conforming in their length to the respective diagonals which denote the stations of their heads and heels. The scantling of the timbers is marked on the moulds, together with the stations of the ribbands and bevelling spots. As each edge of a mould may be used, one mould answers for two timbers, and their opposites. Where rigid economy is of importance, one mould may serve for several futtocks, in which case the various joints are inked on the surface of the mould, and are bored through the mould to the timber in order to obtain its curvature. This method, however, is not to be generally recommended, because a set of moulds will, with care, convert for several ships in succession.

Bevellings.

After the moulds are made, it is customary to take the bevellings of the square body. This subject will, however, be explained generally under the head of cant-timbers, to which we now direct the reader's attention.

Laying off the cant-timbers.

We have already explained that the plane of a cant-timber is vertical, and inclined at a certain angle to the longitudinal plane of the ship; its projection, therefore, in the half-breadth plan, will be a straight line inclined to the middle line.

In the disposition of the cant-timbers, strength and economy should be considered; hence the propriety of diminishing their curvature and bevelling as much as possible. No particular rule can be laid down for their number and disposition, as these must depend on the form of the bow and buttock of the ship. As a general rule, they should be placed as square as possible to the body, and be equally spaced on the main-breadth and middle lines; their sidings, together with the openings between them, or, in other

Hawse-pieces. Knight-heads.

words, their "room and space," should assimilate as near as may be to the square body. The hawse-pieces should be so situated that they may not be too much wounded by the hawse-holes; and in order that the knight-heads may not be injudiciously weakened by the bowsprit, their heads should be separated from the stem, at least in large ships, by a timber of from six to eight inches siding.

It should be remarked, that in the square body every other joint only is laid off, the intermediate joints being drawn in after the laying off may be said to be complete. But in the cant-bodies every joint is laid off, each joint, as in the square body, serving to mould the adjacent timbers on its fore and after sides. Still, if the opening between the timbers of a cant-frame should be very great, it would be more accurate to strike in the openings on the half-breadth plan, and to lay off each timber independent of the other, that is to say, the after edge of the foremost, and the fore edge of the aftermost timber.

Supposing the disposition of the fore and after cant-bodies completed as in the half-breadth plans (Plates CCCCLI. and CCCCLII.), in which the joints of the cant-frames are marked *c*, we proceed to lay them off in the body plan. This is generally done by one of two methods; either by horizontal ribbands, or by level lines. We must here remind the reader, that the square timbers in the body plan, as A, B, C, &c., 1, 2, 3, &c., are not only projections of the same timbers in the sheer plan, but they are absolutely the real shape of the said timbers, on the supposition that the ship was cut asunder athwartships at those stations. Now, if we conceive a vertical section of the bow to be made, not athwartships, but in the direction of the plane of a cant-timber, as W, Plate CCCCLI. fig. 27, and if we project this section to the body plan, this projection will not be the shape of the cant-timber. But if keeping the plane of the cant-timber W fixed at its vertical intersection with the longitudinal plane, we make it revolve round the said intersection as an axis until it comes athwartships, and if in its new position we project it from the sheer plan into the body plan, then, as in the square body, we not only obtain a projection, but also the true form of the timber, to which a mould may be made for trimming it. We shall now explain the manner of performing this ingenious process, selecting as an example the cant-timber W in the fore body.

Laying off by horizontal ribbands.

To lay off cant-timbers by horizontal ribbands. Observe the intersection of the cant-timber, marked W, with the upper horizontal ribband in the half-breadth plan, Plate CCCCLI.; take the nearest or perpendicular distance of this point from the middle line; set this distance off horizontally from the middle line of the body plan, so as just to intersect the corresponding diagonal. In like manner, obtain similar spots from the remaining horizontal ribbands in the half-breadth plan on all the other diagonals in the body plan, and if through the spots so obtained a curve were drawn, this curve would be the projection, not the true shape, of the cant-timber. Next through all the above-named spots on the diagonals in the body plan, draw horizontal lines. In the half-breadth plan, take the distances along the cant-timber from where it intersects the middle line to its intersection with each of the horizontal ribbands. Transfer these distances to the body plan, by setting them off from the middle line, on each of the corresponding horizontal lines before named. Lastly, through the spots so obtained pass a curve, which curve will be the absolute shape of the cant-timber, which has thus been made to revolve round the point W in the half-breadth plan, from its original position, which was oblique to the middle line, until it came into an athwartship position, or square to the middle line.

We have thus delineated the form of the cant-timber at and below the upper diagonal. To obtain its form at the top-side, proceed thus. In the half-breadth plan, square up the intersection of the cant-timber with the main-breadth line, to the corresponding main-breadth line in the sheer plan. Transfer the height so obtained to the middle line of the body plan, through which point draw a level line. In the half-breadth plan, take the distance in the direction of the cant-timber, from its intersection with the middle line to its intersection with the main-breadth line, and set off the same distance from the middle line of the body plan, along the level line just drawn. Proceed in like manner with respect to the top-breadth, top-side, port-sill, or any other similar lines, and we thus procure a series of spots through which the cant-timber may be continued from below.

Ending the timbers.

To obtain the ending of the timber. Draw in the bearding line or the half thickness of the dead-wood in the half-breadth plan, parallel to the middle line. Square up the intersection of the cant-timber with this bearding line, to the bearding line in the sheer plan. Level in this height to the middle line of the body plan, where a horizontal line must be drawn, on which line set off from the half-breadth plan the distance between the intersection of the cant-timber with the middle line, and its intersection with the bearding line. The spot thus obtained determines the ending of the timber.

Bevelling edges.

Having laid off the moulding edge of W, we proceed to lay off its bevelling edges. Parallel to and on either side of the joint W, draw two lines *ac*, *bd*, to represent the sidings of the adjacent timbers. The side extremities of these lines terminate like the joint at the top-breadth line; their midship extremities are bounded by a small line *ab* drawn at right angles to the joint W at its intersection with the middle line.

In our former description we supposed the joint of the timber to revolve round the point W, until it, the joint, came into an athwartship position. Now, instead of imagining the joint only to be thus circumstanced, let us suppose the whole cant-frame to revolve round the point W; in which case the bevelling edges *ac*, *bd*, will become athwartship lines, and *ab* will become a fore and aft line, and may be regarded as the middle line, or rather a small part of the middle line, of the ship. Hence, in laying off the two bevelling edges *ac*, *bd*, we proceed as was before described for the joint, with this exception, that we take the cant distances along *ac*, *bd*, from the points *a* and *b*, instead of, as before, from the point W, at the middle line.

Bevelling of cant-timbers.

The bevelling edges are delineated, as just explained, in the body plan, in which plan they fall without, coincide with, or fall within, the joint; and these three conditions determine whether the timber has a standing, square, or under bevelling. Therefore, across a board the breadth of which is equal to the siding of the timber, draw a line square to its edges. In the body plan, at the various bevelling spots, as sirmarks, port-sills, heads, &c. take the nearest distances of the joint from the bevelling edges, and set these distances on the right-hand side of the board, either above or below the square line, according as the bevellings are standing or under. Then join the points so obtained, and the intersection of the square line, with the left-hand side of the board. The angles formed by the left-hand side of the board, and the various lines across the board, denote the respective bevellings at the corresponding stations in the body plan, which bevellings will be applied square to the curve of the timber.

Heels of cant-timbers.

For trimming and cutting off the heel two bevellings are necessary. The bevelling against the dead-wood is simply the angle formed in the half-breadth plan by the direction of the timber and a fore and aft line, and is therefore taken by placing the stock of a bevel to the cant of the timber, and the tongue to the bearding line.

To obtain the bevelling for cutting off the heel against the stepping. Square up from the half-breadth plan to the sheer plan, the intersection of the joint of the cant-timber with the bearding line. From this point in the sheer plan erect a perpendicular to the keel. Place the stock of the bevel to this perpendicular, and the tongue to the direction of the stepping line, and the required bevelling is obtained.

Laying off by level lines.

To lay off the cant-timbers by level lines. The reader will observe that two processes were necessary in laying off cant-timbers by the horizontal ribbands; for, first, we had to take the square distances of the intersection of the timber with each horizontal ribband from the middle line in the half-breadth plan, and transfer these distances to the corresponding diagonals in the body plan; and, secondly, we had to take the oblique or cant distances of the timber with the same horizontal ribbands in the half-breadth plan, and transfer them to the body plan. But the method of laying off these timbers by level lines is far more simple, only one process being required. Thus, to lay off the joint of W, take the cant distances from the middle line in the half-breadth plan to the intersection of the joint with each level line, and transfer these distances from the middle line of the body plan, along each of the corresponding level lines. A curve through the spots thus obtained gives the true form of the timber.

In considering these two methods of laying off cant-timbers, the reader will remark, that the difference between them consists in this particular, viz. in the first method, or by horizontal ribbands, the heights in the body plan along which the cant distances are set off, are procured from the half-breadth plan; whereas in the second method, or by level lines, these heights are already given in the body plan.

But it may be naturally asked, which is the preferable method? To this we reply, if the student can rely on the fidelity of his labours, let him by all means lay off the cant-bodies by level lines: if, however, he mistrusts the accuracy of his work, let him adopt the plan by horizontal ribbands. The reason of this opinion is, that as the level lines cut the body obliquely, any inaccuracy is more magnified by them than by the diagonals, which cut the body nearly at right angles. With this explanation, we leave the choice of these plans to the discretion of the student.

Bevelling edges.

The bevelling edges are laid off by level lines in the same manner as the joint, except, as in the former method, the cant distances are taken from the points *a* and *b*, instead of from the point W. The bevellings of the timber are taken as explained in the former method.

Cant-timbers in the sheer plan.

To obtain the projection of the cant-timbers in the sheer plan. Square up the intersections of the timber with any of the lines except diagonals, in the half-breadth plan. Diagonals are excepted, because in the half-breadth plan they are not in their natural position, but are supposed to revolve into a horizontal position before they are projected into this plan. Through the spots thus obtained pass a curve, and we obtain the projection required.

This operation is necessary for a variety of purposes. Thus the projection of the fashion-pieces into the sheer plan, shows the boundary of the ends of the transoms. (Plates CCCCLII. and CCCCLIII.) A like projection of the other cant-timbers in the fore and after cant-bodies, shows the arrangement of the heads and heels of the cant-timbers, and their disposition with respect to the bow and after ports.

To lay off the transoms.

To lay off the transoms. As the ends of the transoms are bounded by the fashion-pieces, it becomes necessary to obtain the projection of the fashion-pieces in the sheer and body plans. This is done as previously described with respect to any other cant-timbers. In Plate CCCCLII. the transoms are projected into the half-breadth plan; but as this creates confusion from the multiplicity of lines, it is customary to lay off the transoms by themselves, and to show both sides of the ship. With this view Plate CCCCLIII. is drawn, where fig. 32 represents the plan of the transoms in which the square timbers 29, 31, the buttock-lines 1, 2, 3, 4, 5, the middle line, the bearding of the post, the fashion-pieces, and the wing-transom, are transferred from the half-breadth plan.

In the sheer plan, where the wing-transom intersects the fore part of the rabbet, a line is drawn at right angles to the keel. This line is called the perpendicular to the transoms. A corresponding line is drawn in the plan of the transoms.

Transoms may generally be divided into four kinds. *1st*, Those which have a round-up and a sheer: *2d*, those which have a round-up and no sheer: *3d*, those which have neither a round-up nor a sheer, their upper and lower sides being level both athwartships and fore and aft; they are called horizontal transoms: and, *4th*, those which are square to the stern-post, or rather as square to the body as they can be drawn. These are called cant-transoms; their upper and lower sides are planes.

The deck-transom must necessarily have the round-up and sheer of the deck. We have supposed the wing and filling transoms also to have a round-up and sheer to them, although they are sometimes designed, particularly in small ships, without any sheer. It is customary to distinguish the transoms under the deck-transom as No. 1, 2, 3, &c. They are delineated in fig. 31 as horizontal transoms; occasionally, however, they are canted, as AB, Plate CCCCLII. fig. 29.

Laying off horizontal transoms.

From the nature of horizontal transoms, as previously explained, they will be represented in the sheer and body plans by level lines. (Figs. 31 and 33.) This being done, we have next to make a horizontal section of the ship, at the upper side of each of these transoms, which will of course give the curves to which the moulds are to be made. As the after part of the transoms is terminated either by the fore side of the rabbet, or by the bearding line of the stern-post, in the sheer plan take the distance from the intersection of the upper side of the transom with the fore part of the rabbet, or with the bearding line, to the perpendicular of the transoms. Set this distance off in the plan of the transoms, on each bearding line square from the perpendicular to the transoms, then by joining these two points we obtain the after part of the transom amidships. Again, in the sheer plan, observe the intersection of the upper edge of the transom with each buttock-line. Take the distances of these intersections from the perpendicular to the transoms; transfer the said distances to the plan of the transoms, by setting them off from the perpendicular to the transoms on the corresponding buttock-lines. A curve line passing through these spots will give the form of the upper after-edge of the transom. The accuracy of this curve may be tested thus. In the body plan, take the distances from the middle line of the intersection of the upper side of the horizontal transom with each square timber, transfer these distances from the middle line on each square timber in the plan of the transoms; the spots so obtained ought to correspond with the curve drawn by means of the buttock-lines.

Transoms with a round-up and sheer.

To lay off a transom which has a round-up and a sheer, it should be understood that the mould given to the workmen for trimming the transom to its round-up is generally a circular arc, applied square to the sheer; and that the mould for trimming it to its round-aft is applied flat upon and bent round its upper surface.

In the sheer plan, at the height of the intersection of the middle of the transom with the fore part of the rabbet of the post, draw a line to the sheer of the transom. Continue this sheer line until it meets the perpendicular to the transoms, at which point draw a line downwards at right angles to the sheer line. Fig. 31.

In the body plan, at the height of the upper side of the transom amidships, draw a level line; draw also a circular arc to the round-down of the transom, square to the sheer, the before-named level line being a tangent to this arc;

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at each buttock-line take the distances of the level line from the arc, and set them off in the sheer plan, upon the line drawn square to the sheer of the transom, below the point of intersection of the square and sheer lines. From these points draw lines parallel to the sheer, and where they cut the corresponding buttock-lines, draw a curve which will represent the round-down of the transom below the sheer. To transfer this curve to the body plan, level in its intersection with each buttock-line in the sheer plan to the corresponding buttock-lines in the body plan; through the points thus obtained pass a curve. To delineate the curve in the plan of the transoms to which the mould is to be made, proceed thus. In the sheer plan, observe the points of intersection of the sheer-lines with the buttock-lines; take the distances of these points in the direction of the sheer to the line drawn at right angles with the sheer. Transfer these distances to the plan of the transoms by setting them off on each buttock-line, from the perpendicular to the transoms. Through the points thus obtained pass a curve, which will represent the mould for the upper after-edge of the transom. This curve may be corrected, by means of the square timbers, on the principle before explained with respect to the horizontal transoms. We may here remark, that, strictly speaking, the buttock-lines in fig. 32 should have been expanded, by taking their distances from the middle line in the body plan round the curve of the transom, and transferring them to the plan of the transoms. But as the variation would be very trifling, this operation is unnecessary in practice.

Laying off a cant-transom.

To lay off a cant-transom. In the sheer plan, from the perpendicular to the transoms, take the distances along the upper side of the transom to the intersection of the upper side with each buttock-line and with the bearding line. Set these distances off in the plan of the transoms, on the corresponding buttock and bearding lines, from the perpendicular to the transoms. A curve through these spots will give the form of the transom.

To test the accuracy of this curve, in the sheer plan project the heights of the intersections of the upper sides of the transom with the square timbers and buttock-lines, to the corresponding timbers and buttock-lines in the body plan. A curve passed through the spots thus obtained will represent the transom in the body plan. Next, in the sheer plan, from the perpendicular to the transoms take the cant distances of the intersections of the transom with the square timbers and with the fashion-piece. Set off these distances in the plan of the transoms, from the perpendicular to the transoms, and through the spots draw lines parallel to the said perpendicular In the body plan take the horizontal distances from the middle line, to the intersections of the transoms with each square timber and square fashion-piece. Lastly, in the plan of the transoms set off these distances from the middle line on the lines just drawn, parallel to the perpendicular of the transoms. The spots thus obtained should correspond with the curve previously drawn by means of the buttock-lines.

Bevellings of the transoms.

The bevellings of the transoms may be taken in the sheer plan from the buttock-lines, by placing the stock of the bevel in the direction of the upper surface of the transom, and the tongue in the direction of the buttock-line. In this case the stock of the bevel must, when applied, be placed in a fore and aft direction.

If it be thought more desirable to set off the bevellings square to the curve, it will first be necessary to lay off the under sides of the transoms, as before described with respect to their upper sides. This being done, in the plan of the transoms take the shortest distance apart of the upper and lower sides of the transom, at any assigned station. This distance denotes how much the transom is under a square in its depth, and therefore determines the bevelling at the assigned station.

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Margin of the wing-transom.

With respect to the wing-transom, it must be observed, that the margin is of a parallel depth all round. The bevelling of the margin conforms to the direction of the fore side of the rabbet of the post. Below the margin the bevellings are taken as before described.

Moulds to the transoms.

Moulds may be made to the after lower edges of the transoms, which moulds are applied on the under surfaces, through the spots obtained from the bevellings.

Laying off the side counter-timber.

We shall next proceed to lay off the side counter-timbers. We have already explained the manner of obtaining the projection of the after edge of the side counter-timber in the sheer and body plans. The fore edge is drawn in the sheer plan by setting off from the after edge the intended size or moulding of the timber. To draw the fore edge in the body plan, square down from the sheer plan the points where it cuts the various level lines, to the corresponding level lines in the half-breadth plan; take the half-breadths of the ship at the points thus obtained, and transfer these half-breadths to the body plan on the corresponding level lines. Hence we obtain the projection of the fore edge of the side counter-timber in the body plan.

Now it is evident that the lines in the sheer plan representing the fore and after edges of the side counter-timber do not give its true form, and that, on account of the tumbling home of the side, a mould made to the above lines would be shorter than the timber itself. Hence it becomes necessary to expand the timber, by making it revolve on a horizontal axis at the heel until it becomes vertical. This process is thus performed. In the body plan draw a straight line, about three fourths of an inch from the upper and lower part of the fore edge of the side counter-timber, as seen in fig. 33, Plate CCCCLIII. This straight line represents the upper side of the mould; its lower end terminates on the level line of the wing-transom at the side; it is marked, in figs. 31 and 33, "base." Having all the level lines marked on this line, imagine it to revolve round its lower end until it comes into a vertical position; mark in the level lines in their new situation, and transfer them to the sheer plan, in which plan the intersections of the edges of the side counter-timber with the original level lines are to be squared up by perpendicular lines to the new level lines. Through the points thus obtained draw curves for the fore and after edges of the side counter-timber in their expanded or vertical position. To these curves the mould must be made.

Next, in the body plan, take the distances along the various level lines, from the straight line representing the mould, to the fore and after edges of the timber. In the sheer plan let the distances just taken from the body plan be marked upon the fore and after edges of the mould at the new or expanded level lines. When the mould is applied on the timber, these distances or spilings are set off in the direction of the tumbling home. After the outside of the timber is completed, the inside may conform to the scantling of the top-side.

We may observe, that instead of the spilings being marked on the mould, brackets are sometimes nailed on the mould, corresponding to the spilings. These brackets are shown in fig. 31, marked *b*. In this case, when the outside of the side counter-timber is completed, the under edge of each bracket exactly conforms to the timber. For the sake of illustration, brackets are also shown in fig. 29.

Bevellings.

To take the bevellings of the side-counter timber from the half-breadth plan, place the stock of the bevel to a fore and aft line, and the tongue to the horizontal round-aft of the various level lines. In applying these bevellings, the stock is placed on the mould to the level lines, and the tongue is placed in the direction of the tumbling home.

We have thus described some of the principal operations in laying off. We have endeavoured rather to illustrate the general principles than the details of the subject; and although in this short treatise many things are necessarily omitted which are of importance, as illustrative examples of the art of laying off, it will be found to embrace all those points which are likely to occur in the ship-building of the present day, or at least render them comparatively easy.

### *Practical Building.*

Ship-building.

We now come to the consideration of the branch of our subject to which the term "ship-building" may be correctly applied; that is, the mechanical construction of the fabric of a ship. We have already, in the preliminary remarks to the "Laying Off," described generally the relative position of the principal timbers which compose the frame-work of the hull, and that are necessary to give the contour of the body. Technically speaking, it is usual only to apply the term timbers to the frame-timbers of a ship. We shall, however, for the sake of perspicuity and brevity of description, adopt the term as one of more general application, and use it to designate the larger pieces of woodwork which enter into the construction of the hull. Previously to any detail, we shall mention severally the various internal timbers used as supports and ties to the frame, and the combinations of external and internal plank by which it is covered. This is necessary in order to render the subsequent descriptions intelligible to those unacquainted with the technical names used in ship-building. We must also refer our readers to the plates which are intended to illustrate this part of our article, for much information that may be more easily obtained from them than from description.

Definitions.

The apron is fayed (or fitted) to the after side of the stem, and is intended to give shift to its scarphs; the lower end scarphs to the dead-wood. The keelson is an internal longitudinal range of timbers, situated immediately over the keel, and fayed to the inside of the throats of the floors, its use being to give shift to the scarphs of the keel, and to secure the frames down to the dead-wood. The foremost end of the keelson scarphs to the stemson, which is intended to give shift to the "boxing scarph," or connexion between the stem and keel. The after end of the keelson formerly scarphed to the sternson, a timber which, in a similar manner aft, strengthens the connexion between the keel and stern-post. The keelson is now generally rounded off short of the heel of the sternson, and latterly the boxing scarph of the stem has been discontinued. The additional keelsons, sometimes also called sister-keelsons, are timbers brought on the inside of the frame on each side of the keelson, to receive and to diffuse the weight of the main-mast. Timbers which cross the stemson or keelson forward, for the purpose of connecting the two sides of the ship, are called hooks. Those which are placed to receive the ends of the decks are called deck-hooks. Timbers which for a similar purpose cross the sternson or keelson aft, are called crutches. These hooks and crutches are frequently combinations of timber, or of timber and iron They are then formed of two half hooks called ekeings, and the middle or connecting piece. Timbers which are fayed to the inside of the frame, or upon the inside plank, solely for the purpose of supporting the frame, are called riders. Timbers which in a square stern fay to the fronts of the transoms, and run forward to strengthen the connexion between the stern and the ship's side, are called sleepers. The two sides of the ship are prevented from collapsing by transverse timbers called beams, which are generally connected at their ends to the ship's side by knees either of wood or iron. The beams are spaced, first with reference to the mast-holes, to the hatchways, ladderways, or passages from deck to deck, and other arrangements connected with the economy of the ship, and then in reference to the ports, that they may afford support to the artillery.

Those beams which do not extend from one side of the ship to the other are called half-beams; they are placed in intervals between the beams that would otherwise be too devoid of support for the plank of the deck, which is laid on the upper surface of the beams, and called the flat of the deck. Timbers worked round the interior of the ship for the purpose of receiving the beams of the several decks, are called shelves to these decks; and those timbers which are worked upon the ends of the beams, and also round the interior of the ship, are called water-ways; thus, gun-deck shelf, gun-deck water-way, or upper deck shelf, upper deck water-way. Chocks, internally, are timbers brought under the ends of the beams, or under the shelf that is immediately beneath the beams, to support them, and to receive the bolts of the knees which connect their ends with the ship's side. A chock is a name applied very generally to any piece of timber filling an interval, or supplying a deficiency in any of the combinations, either of timber, or of timber and iron. Bits are timbers projecting through the decks, either vertically or slightly inclined, and are used for facilitating the management of the ropes for the rigging. The riding-bits are for securing the cable when the ship is riding at anchor. Standards, generally, now, are timbers used for supports, as to the bits. On the old system of building, standards were sometimes placed where they could only act as ties, as the standard to the stern. There were also standard-knees on the decks, both to support and tie the ship's sides.

The plank, both external and internal, is of various thicknesses: a thick strake, or a combination of several thick strakes, being worked wherever it has been supposed that the frame required particular support; as internally, over the heads and heels of the timbers; both externally and internally between the ranges of ports; and internally, to support the connexion of the beams with the side.

Of the internal planking, the lowest strake or combination of strakes in the hold is called the limber-strake. A limber is a passage for water, of which there is one throughout the length of the ship on each side of the keelson, in order that any leakage may find its way to the pumps; and it is from this that the limber-strake takes its name. A strake of planking is a range of planks abutting against each other, and extending, excepting in particular cases to be afterwards mentioned, the whole length of the ship.

The whole of the plank in the hold is called ceiling. Those strakes which come over the heads and heels of the timbers are worked thicker than the general thickness of the ceiling, and are distinguished as the thick strakes over the several heads. The strakes under the ends of the beams of the different decks, and down to the ports of the deck below, if there be any ports, are called the clamps of the decks to the beams of which they are supports; as the gun-deck clamps, middle-deck clamps. The strakes which work up to the cills of the ports of the several decks are called the spirketing of those decks, as gun-deck spirketing, upper-deck spirketing. The upper strakes of planks, or assemblages of external planks, are called the sheer strakes. The strakes between the several ranges of ports, beginning from under the upper-deck ports of a three-decked ship, are called the channel-wale, the middle-wale, and the main-wale. The strake immediately above the main-wale is called the black strake. The strakes below the main-wale diminish from the thickness of the main-wale to the thickness of the plank of the bottom, and are therefore called the diminishing strakes. The lowest strake of the plank of the bottom, that of which the edge is in the rabbet of the keel, is called the garboard. In merchant-ships the rabbet is generally worked out of the middle of the side of the keel, and not, as in ships of war, at the upper part of the side. Several methods of working this garboard, and the lower strakes of the bottom, have been lately adopted, both in the royal and in the mercantile shipping. One of these plans, see fig. 37, Plate CCCCLIV., called "Lang's safety keel," from the inventor, Mr Lang, the master shipwright of Woolwich yard, has, we believe, been very extensively applied to the keels and garboards of steam-boats; and several of Her Majesty's ships have been built with their garboards so worked. A represents the keelson, B the floor-timber, C the keel, D the outer keel, E the false keel, F, F solid pieces continued fore and aft the vessel, as substitutes for the chocks on the floors and the planking of the bottom.

The pieces of timber, either secured or placed to receive the heels of the several masts, are called steps, as the main, fore, or mizen step. The heel of the bowsprit is also, in small ships, sometimes on a step. In general, the bowsprit steps on a frame-work, called the bowsprit partners. The frame-work of timber which is formed round the mast-holes in each deck is called mast-partners. Partners, generally, are the principal timbers in a framing formed for the support of any thing passing through a deck, as the masts and capstans. Carlings are pieces of timber forming a part of the framing for a deck, lying in a fore and aft direction, and from beam to beam, to receive the half beams, to aid in supporting the deck, and for various other purposes. Ledges are pieces also forming a part of the framing of a deck, generally smaller than carlings, and which are placed athwartships in the same direction as the beams. Coamings are pieces of timber generally faying on carlings, and raised higher than the flat of the deck, forming the fore and aft boundaries to openings in it, as hatch or ladder ways. Headledges in the same manner form the athwartship boundaries to these several openings.

The knee of the head, which has been already incidentally noticed in the laying off, is a prolongation of the fore part of the ship, principally of use as a security for the bowsprit, which is firmly lashed to it by portions of the rigging, called the gammoning and the bob stays. The checks are knees fayed on each side of the knee of the head, and also against the bows, in the direction of the sheer, in order to afford support to the knee of the head.

We do not profess that this is a perfect list of the components of the hull of a ship. We have merely enumerated some of the more important pieces, or combinations, of timber, the names of which may occur again in our further remarks. It would be impossible, in an article so limited in extent as the present, to enter much into the detail of practical building. We shall content ourselves with endeavouring to illustrate some few general principles, which may guide the practical builder in his arrangements.

There are several very voluminous works explanatory of the detail of practical ship-building. By far the most perfect information on the practice, as it exists in Her Majesty's yards, will be found in the very excellent plates to Fincham's Outline of Ship-Building. We believe the most modern work on the construction of the mercantile navy is Hedderwick's Treatise on Naval Architecture, which contains very minute details of the practical building in the merchants' yards.

Disturbing forces.

We shall now consider the most important disturbing forces which are in action, either to injure or to destroy the several combinations of the hull of a ship. Some of these forces are inherent to the form of the body, while others are only brought into action when the body is in motion. In the theoretical portion of this article it has been explained, that when the ship is at rest on still water, the total weight of the vessel is equal to the upward pressure of the water; but it does not necessarily follow, that the weight of every portion of the vessel shall be equal to the upward pressure of that portion of water which is immediately beneath it. On the contrary, the shape of the body is such, that these weights and pressures are very unequal. We will suppose the vessel to be divided by transverse vertical sections into a number of laminæ of equal thickness, which will all be perpendicular to the vertical longitudinal section. It is evident that the after laminæ comprised in the overhanging stern above water, and the fore laminæ comprised in all the projecting head, also above water, cannot be supported by any upward pressure from the fluid, but their weight must be wholly sustained by their connexion with the supported part of the ship. The laminæ towards each extremity immediately contiguous to these can evidently derive a very small portion of their support from the water; but as their stations in both the fore and the after bodies approach towards the middle of the ship's length, a greater proportionate bulk is immersed, and the upward pressure of the water is increased; so that at some certain station from the middle of the length in each body, the upward pressure will equal the weight of the superincumbent lamina, and all the laminæ comprising that portion of the body between these two stations will be subjected to an excess of pressure above their weight, tending to force them upwards, which upward pressure will be the greatest at the lamina having the greatest transverse area of section.

Now, as we know that the total pressure upwards is equal to the total weight of the vessel, this excess of upward pressure, to which the midship part of the length of the body is subjected, must be just equal to the excess of weight over the upward pressure in the parts of the vessel before and abaft those laminæ at which we have represented the pressure and weight to be in equilibrio.

A ship floating at rest may be considered as a beam loaded at each extremity with a weight, and supported at two points in its length, which are at some distance on each side of its centre, while the part between its points of support is subjected to a force acting upwards equal to the sum of these two weights. A beam thus acted upon would have a tendency to assume a curved shape; and it would gradually assume such a form, as the effect of the weights and forces overcame the rigidity of its particles. This is precisely the effect of the action on the ship; and the upward curvature, when it does ensue, is what is technically called "hogging." **Hogging.** As long as the fastenings remain unaffected from the continued operation of the disturbing forces, and the abutments of the several timbers and plank composing the fabric also maintain their close contact, this curvature will not take place; but when these become partially deranged, the upward pressure, and the downward gravitation of the several portions of the body, can no longer be considered as tendencies only to deterioration of the fabric, but as active agents in the work of destruction.

Sagging.

It does not necessarily follow, from all that has been said, that the hogging will give a regular curvature to the form: on the contrary, the various actions of the weight and pressure will produce varied effects. Thus, before the introduction of the additional keelsons, the body frequently "sagged," the contrary or opposite curvature to hogging, under the weight of the main-mast.

A corresponding action to that described as hogging, takes place in relation to the breadth of the vessel, especially on account of the weight of the ordnance; so that the central portion of the body is subjected to an upward pressure forcing it above the water, and the outer portions are strongly acted upon by their unopposed gravity immersing them beneath it. The effects of this action will be modified by the form of the vessel; longitudinally it produces the upward curvature that we have described, and transversely it either tends to a separation of the sides both above and below throughout their extent, or, if the "tumbling home" be great, a separation at the main breadth and below it, and a collapsing of the sides above it.

Horizontal pressure of the water.

Another force tending to alter the form of the ship when she is at rest, arises from the horizontal pressure of the fluid on the surface below the load water-section, which tends to reduce the dimensions below that plane, and therefore to add to the hogging.

Though these are the disturbing forces when the ship is at rest, their action is not confined to that state; they are also in operation when she is in motion. Other injurious effects are produced by, and belong only to, a state of motion.

Pitching and rolling.

If the surface of the sea be very uneven, so that the ship's passage may be over its undulations, her support becomes variable, and the opposing forces of upward pressure and gravitation will have a tendency to produce a corresponding undulation in the body.

Force of the waves.

When the ship is on a wind, the lee side is subjected to a series of shocks from the waves, the violence of which may be easily imagined, from the effect they sometimes produce in destroying the bulwarks, tearing away the channels, and washing away the boats, &c. The lee side is also subjected to an excess of hydrostatic pressure over that upon the weather side, resulting from the accumulation of the waves as they rise against the obstruction offered by it to their free passage. These forces tend in part to produce lateral curvature. Also in this inclined position the forces which, when she is upright, tend to produce hogging, now partly contribute to produce lateral curvature. By experiments made on Her Majesty's ship Genoa, in the year 1823, by Mr Moorsom, formerly a member of the late School of Naval Architecture, he ascertained that this lateral curvature amounted to one inch and a half on each tack, making an alteration of form to the extent of three inches, from being on one tack to being on the other.

Tension of the rigging.

The strain from the tension of the rigging on the weather side when the ship is much inclined, is so great as frequently to cause working in the top-sides, and sometimes even to break the timbers on which the channels are placed.

Taking the ground.

Ships also, especially those designed for the service of commerce, are liable, either from intention or from accident, to take the ground. This contingency must be provided against, as has been already mentioned, in the laying off.

These are the principal disturbing forces to which a ship is subjected. It must be remembered that they are in almost constant activity to destroy the connexion between the several parts of the fabric; and that whatever "working" may be produced by their operation, tends most materially to increase their effect; because the disruption of the close connexion between the several parts admits an increased momentum in their action on each other, and the destruction proceeds with an accelerated progression; while the admission of damp, and the unavoidable accumulation of dirt, soon generate fermentation and decay. To make a ship strong, is at the same time to make her durable, both in reference to the wear and tear of service, and the decay of materials. But there is one very important consideration which should be remembered in the construction of all fabrics with so perishable a material as timber; it is, that all strength beyond that which is necessary to insure durability to the fabric equal to the durability of the material, is a waste both of labour and material; or, in other words, if a ship, built at an expense of L.40,000, will last twelve years, it would be false economy to expend L.60,000 in building one to last fifteen years.

If, by any means, the durability of wood should be much increased, it would be also necessary to increase the strength of the ships built of it, that the durability of the construction might equal the durability of the material.

Hogging as it affects the structure.

We see from this outline, that the forces which cause the hogging, which are the most important disturbing influences, commence their action at the moment of launching of the ship, and are thenceforward in constant operation. This curvature can only take place by the compression of the materials composing the lower parts of the body, and by the elongation of those composing the upper parts. We therefore have to determine the divisional line separating these two actions, and to form the combinations above and below this line, to offer opposition in accordance to the different directions of the strains to which they will be subjected. Dupin, in his able paper on Seppings' Diagonal System, fixes this line of inaction at about the surface of the water. According to the accepted theory of the strength of bodies, it would be situated lower than this in large ships; but the horizontal pressure of the water, already mentioned, makes the case of a body supported on a fluid an exception, and the station assumed by Dupin must approximate nearly to the correct position.

The portion of the ship about the surface of the water must therefore be considered in the light of a foundation to the fabric, and should be strengthened, not only to resist the inequalities of the strains to which it will be itself subjected, especially when the ship is in motion, but also to constitute it a firm basis, from which to extend supports to those portions of the hull both above and below it, that will be subjected to yet greater disturbing forces than itself.

In order to resist the tendency to hogging, the object of the ship-builder should be to form an incompressible mass below this line of inaction, and to render the body rigid and inextensible above it; hence the immense advantage gained from Sir Robert Seppings' plan of filling in the openings in the lower part of the frame, and especially of the plan which he introduced of filling them with cement that so far exceeds any timber in hardness. The various abutments of this part of the body should be as closely fayed as possible. In the dead-wood the buts of the shifts should all be cut off square to the joints, and the abutting surfaces multiplied by the interposition of dowels in these joints, the abutments formed by which are certain, and hence the advantage of dowelling the keelson, rather than scoring it over the floors. In this part of the body the length of the scarphs is not of so much importance as the close abutment of the lips, to insure which the scarphs should be keyed. The keel scarphs are an exception to these remarks, as they require additional and different security, from being external openings.

The tendency of the hogging will be to alter the angles formed by the post and the stem with the keel; therefore it is necessary to strengthen the connexions of these timbers by every means which will oppose this tendency, as elongating all the shifts, hooking all the scarphs, and judiciously distributing and supporting all the fastenings. Hence the advantage of a dead-wood knee, as adding most considerably to the strength of the connexion abaft, and enabling a more regular and advantageous application of the bolts to be made. This object of strengthening the connexion of the post and stem with the keel, is therefore the consideration to be attended to in shifting the after shifts of the after dead-wood and the sternson, and in shifting the fore dead-wood with the stem, apron, and stemson, and also in disposing the fastenings which pass through these timbers. The old plan of running the keelson aft to scarph with the sternson added materially to the tie. Another important support to the stern in line-of-battle ships, is a carling brought up under several of the after beams of the gun-deck, and secured to them; its after end being connected to the head of the sternson by side-plate knees.

There is more necessity for attention to the support of the stern than to that of the bows, because, when a ship is under weigh, the after part beneath the water, as it has been already explained, is deprived of much of the pressure to which it was subjected when at anchor, and therefore the effect of the gravitation is less opposed. Hence also the "cambering," or curving outwards, of the stern-post. The cambering of the post might, however, be greatly prevented, by a tie-bolt connecting it with several of the after beams of the lowest deck, among which the strain would be diffused by the carlings between them. This might now be done even in line-of-battle ships, as they carry their orlop-beams right aft.

Since compression is the action to which the lower part of the body is subjected, we see the evident inutility of sacrificing economy in order to obtain length of shift for the plank of the bottom, or, indeed. of making any great sacrifice of plank for this purpose below the surface of the water, excepting for the foremost and aftermost shifts, at the bluff of the bow, and under the buttock.

The deck below the water, that is, the orlop, in ships of the line, and the lower deck in frigates, though near the neutral line, are below it; and therefore the action to which they are subjected is compression, to resist which the ranges of carlings should be maintained from one extremity of the vessel to the other, and all their abutments should fit as closely as they can be got in place.

We have mentioned the keel scarphs as an exception to our general remarks. They are usually in England vertical scarphs, with coaks raised in the lip-ends of the scarphs, to fit into mortices sunk for their reception in their but-ends. These coaks serve as a stop to the caulking, and, in connexion with the scarph-bolts, are well devised, in the event of the curvature of the keel, to enable the scarph to partake of it, and to prevent leakage. In France, and generally in the foreign yards, the scarphs of the keel are horizontal. Very lately the horizontal scarphs have been adopted in the English service. We consider the vertical scarph much to be preferred, for the reasons above stated.

In those parts of the ship situated above the line of in-action, every means should be taken to multiply longitudinal ties. Since, in order to resist compression in the lower parts of the body, the openings are filled in, and form a solid mass; to produce the opposite effect, that is, to enable the frame to resist extension, it should be chain-bolted together towards the upper parts of the body, wherever the continuous range of bolts can be placed not to interfere with the in and out fastenings; as opposite the openings between the shelf and water-way of the several decks just above the scuppers. This plan has been pursued in several of the modern ships. The shifts of the different wales, spirketings, and clamps, should be long, the regular shift of the buts most carefully maintained, and the buts of the inside assemblages made to give shift to the buts of those outside. Sir Robert Seppings' plan of supporting the fastenings, and compensating for the weakness of the buts in some of the principal assemblages of plank, by dowels into the timbers in the strakes immediately above and below the buts, is of great utility. Also the plan of connecting several strakes together by tie-bolts placed opposite the openings between the timbers in the frame, where they could not interfere with any fastening, was admirably adapted to diffuse strength, and to prevent longitudinal working of the planks, or the sliding of one edge past another, from any partial weakness. These might advantageously be much more extensively applied than was contemplated in the instructions issued by Sir Robert; indeed, to all the internal assemblages of plank in which they can be driven.

The planking.

Plank is either worked in parallel strakes, when it is called "straight-edged," or in combinations of two strakes, so that every alternate seam is parallel. There are two methods of working these combinations, one of which is called "anchor-stock," and the other "top and but." The difference in their appearance will be best seen by a reference to Plate CCCCLVIII., fig. 43. The difference in the intention is, that in the method of working two strakes anchor-stock, the but of one strake always occurs opposite to the widest part of the other strake, and there is consequently the least possible sudden interruption of longitudinal fibre arising from the abutment; therefore this disposition of plank is used where strength is especially desirable. In top and but strakes the intention is, by having a wide end and a narrow end in each plank, to approximate to the growth of the tree, and to diminish the difficulty of procuring the plank.

The shift of plank is the manner of arranging the buts of the several strakes. In the ships of the royal navy the buts recur with intervals of three whole strakes between. In merchant-ships there are often not more than two whole strakes between the recurrence of the buts. The regularity of the shift of plank is far more carefully maintained in English building-yards than in those abroad.

The fastening of the plank is either "single," by which is meant one fastening in each strake through each timber of the frame which it crosses; "double," or two fastenings in each timber; and "double and single," meaning alternations of the double fastening in one timber with the single fastening in the next.

This fastening consists generally either of nails or treenails, excepting at the buts, which are secured by bolts. Several other bolts are driven in each shift of plank as additional security. These additional fastenings are far more plentifully diffused in the royal yards than in those of private builders. Whatever system of securing the plank may be determined upon, great care should be taken to guard against a repetition of fastening, which will otherwise occur from the various bolts that will come through the bottom as securities to the riders, shelves, water-ways, knees, and bolts connected with the service of the guns. These bolts should evidently, for economy, and also for the sake of avoiding unnecessarily wounding the timbers, supply the place of the regular fastenings of the plank.

Before copper sheathing was introduced, iron was used for fastening. Since then, either bolt-nails cast of a mixture of zinc, copper, and grain tin, technically called "metal," or pure copper bolts, are used in addition to the treenails. Experiments are now being made in Holland to protect iron bolts, used for fastening the plank on ships' bottoms, from the galvanic action induced by the copper. The bolts are punched within the wood, and covered with a cement made of equal parts of lignum vitæ saw-dust, smiths' ashes, and "minium." In France also several ships' bottoms have lately been iron-fastened, with Roman cement over the bolts; they were then felted and sheathed, the sheathing being secured with copper nails, and the bottom afterwards coppered. This inquiry as to the possibility of applying iron for the fastening of ships in connexion with the copper sheathing, is of great importance, as, independently of the difference in the expense of the two metals, the difference in their tenacity is as 995 to 546, or copper is only about $\frac{11}{20}$ths of the strength of iron, or little more than one half.

The plank in the royal yards is not usually permanently fastened for some time after it is trimmed and brought on to the bottom of a ship, but is temporarily secured by Blake's screws, and allowed to season and shrink. About one strake in eight or ten is left out for the purpose of making good the shrinkage and refaying the strakes. Without this precaution there would be such an alteration of edge as would throw the holes made for the temporary securities out of the ranges of the strakes; but this precaution being taken, it is very seldom that the alteration of edge is such as to require new holes, especially as the iron screw eye-bolts used for this temporary fastening are of much smaller diameter than the permanent treenail fastening, and therefore the holes for the screws will make good holes through the plank for the treenails.

Temporary fastening.

This method of securing the planks in a temporary manner is of immense advantage in enabling them to be brought into close contact with the timbers, in the saving of bolt-fastenings, and in causing a good and regular seam to be given for the caulking.

The circumference of the bottom being much larger at the midship part than towards the extremities, that is, at the bow and buttock, the lines for the strakes of plank must close, and the strakes taper as they recede from midships. They also acquire an upward curve, called "sny," which renders it difficult to work the plank. When the sny becomes too great, a strake is ended short of the rest, and this is termed a "stealer," as it diminishes the sny for the succeeding strakes. Under the buttock it is often necessary to work some of the after plank wider at the after end, which has the same effect of diminishing the sny of the following strakes. "Hang" is the exact reverse of "sny." It mostly occurs in working plank on the inner surface of the timbers, and outside above the main breadth.

Sny.

Hang.

The various plans for fastening the plank and for securing the buts will be most easily understood by a reference to Plate CCCCLVIII. fig. 43.

Caulking.

When the plank is worked and fastened, the seams, or the intervals between the edges of the strakes, are filled with oakum, or "caulked," with such care and force, that the oakum, while undisturbed, is almost as hard as the plank itself. If the openings between the strakes were of parallel width throughout the thickness of the plank, it would be impossible to make the caulking sufficiently compact to resist the water. The inner part of the edges of contiguous strakes should be in contact throughout their length, and from this contact the edges should gradually recede from each other to the outer surface of the plank, so that at a thickness of about ten inches they would be about $\frac{10}{16}$ths of an inch apart; that is, about $\frac{1}{16}$th of an inch seam for every inch in thickness of plank. The practice in the royal yards is to allow a double thread for every inch in thickness of plank, and an additional double thread for every five inches; besides which, one, or sometimes two, threads of spun-yarn are driven in as a bottom to the oakum. In the merchant-yards on the Thames, and where the larger merchant-ships are built, the caulking is nearly the same as in the government establishments. But in the smaller ships built at the outports, the oakum is seldom "bottomed" home to the inner edge of the seam, the consequence of which is, that the uncovered edges of the planks decay, and the second caulking drives the oakum through, after which the seams cannot long be kept tight.

It is the generally received opinion, that however the French may have excelled us in designing the body of a ship, our practical building has always been incomparably superior to theirs. In so far as the skill of the workman is involved in this opinion, we believe it to be strictly correct.

The workmanship of English mechanics is probably unrivalled, certainly not surpassed by that of any other mechanics in the world, either in solidity or in neatness of execution; but we cannot in justice urge the claim of superiority further.

However weak the French prizes taken during the last century may have been from defective workmanship, the materials were in several instances much more judiciously combined for the purpose of obtaining strength than in the contemporary ships in our service. Indeed it was not until after Sir Robert Seppings became surveyor of the navy, that the absurdity of having the sheer of the ship and the sheer of the ports different from each other, was discontinued. The effect of this difference in their sheer was, that the assemblages of thick strakes brought round the sides for the purpose of strengthening them, were actually cut off from being crossed by the sheer of the ports. In the majority of the French and Spanish ships taken at so early a period as the middle of the last century, the sheer of the ports was the same as the sheer of the ship, consequently the whole strength of the thick strakes was preserved. The shelf was also originally copied from the French; and though they have now discontinued it, it was at the period of its introduction an important improvement. Also we have only followed them in the adoption of iron knees for the security of our beam-ends. In making these animadversions, we speak wholly of the past. For many years British ships have been unequalled for strength, as well as for perfection, of workmanship.

It has become almost a fashion to decry the improvements introduced by Sir Robert Seppings. It would be well, perhaps, to remember the complaints continually made, of the weakness of the ships before he became surveyor of the navy, and to contrast the fleets of England at that time with the fleets which he left in the service when he relinquished the surveyorship. There is no doubt that many of his plans were imperfect, and are susceptible of great improvement. No change ever yet was made, or ever will be made, that was not and will not be susceptible of yet further improvement.

Decks.

We have already mentioned the decks which are situated below the line of non-action; those above it must all be considered as most valuable longitudinal ties. Their sheer has been most properly much diminished within these last twenty years. It is evident, that for rigidity, decks without any sheer would be advantageous. The sheer was probably given them to facilitate the run of water to the scuppers, and may perhaps be desirable for this purpose; but certainly, as strength is lost by their curvature, the sheer of the decks should be as little as possible. It may be objected, that perfectly straight decks would be injurious, or at least very unsightly, in the event of hogging taking place. The objection is not valid; strength must not be sacrificed in order to prepare for the occurrence of a contingency which we are endeavouring to prevent, and which evidently may be prevented for a great length of time, since the various improvements introduced during the last five-and-twenty years have certainly almost wholly prevented the weakness in ships, which was before such a source of constant complaints.

Fastening decks.

The only consideration, in fastening decks, is to preserve their contact with the beams, and to withstand the action of caulking: more than enough to effect this object is useless, and therefore the numerous bolts introduced with the system of diagonal decks were unnecessary. It may probably be proper to observe, that the harder the material used for the flat of decks, the greater should the quantity of fastening be, as there will be less yielding of the edge to the caulking; and although it is usual to allow more seam for caulking planks of a hard than of a soft material, the caulking will bring far more strain on the fastenings of the harder than on those of the softer; besides which, strictly speaking, though it is not practically expedient, seam should depend upon thickness alone. It may not be improper to mention here, that the quantity of fastening must increase with the thickness of the plank, whether of deck or bottom, which is to be secured; for the set of the oakum in caulking will have the greater mechanical effect the thicker the edge.

Diagonal deck.

The diagonal deck, whatever advantage it might have been presumed to possess in other respects, was certainly a great loss of strength in as far as longitudinal tie was involved, and, we consider, has been most judiciously discontinued. The rapid deterioration arising from the wear occurring across the fibre of the wood, with the additional inconvenience, that the partial wear along the working passage of the deck, by crossing every strake, involves the shifting the whole flat, is alone a strong argument against any alteration in the system of laying the strakes of deck fore and aft. Mackonochie proposed to lay decks in three layers, one diagonally from starboard to larboard, another diagonally from larboard to starboard, and an upper layer fore and aft. He also proposed a somewhat similar system for the outside plank, from the garboard to the wales. Merchant-vessels have been built in America, and boats and steam-vessels in this country, on this system of layers of planks laid diagonally.

Sir Robert Seppings was apparently aware of the important tie which a deck is to a ship, as he retained some of the midship-binding strakes, and introduced dowels to render their connexion with the beams and with the extremities of the vessel more perfect and more unyielding than could be effected by the old plan of scoring down, with its attendant evils from the shrinkage of the materials and neglect of workmanship.

The aftermost and the foremost beams of each deck might be advantageously made to afford support to the projecting bows, and especially to the raking sterns of the modern ships, by connecting the bow and stern timbers to them at each deck by long tie-bolts passing through several beams, clenched on the aft side of the aftermost forward, and on the fore side of the foremost of them aft. These beams should have several ranges of carlings let down between them, to diffuse the strain. This would be far preferable to forelocking the bolt on the fore side of each beam; first, because, generally speaking, the strain would only fall upon one beam, that which was most closely forelocked; and, secondly, because by experiment we find that the size of the bolt being the same, the forelock would give way, or the bolt break at the forelock-holes, under about one half the strain which the clench would withstand.

Several Dutch ships have been built with a round-up to the decks in the direction of the length; the keels of the same vessels were built to sag or curve downwards towards the midships of the length, and the fore and after extremities were so constructed that the longitudinal vertical section should form an elongated ellipse. Only steam-boats have, we believe, ever been built on this plan.

Beams.

The beams which support the deck have a curve upwards, in the direction of their length, to the middle of the ship, called the "round-up." This is for the purpose of strength, and for the convenience of the run of water to the scuppers. Beams are single piece, two, three, or four piece (Plate CCCCLIV., figs. 39, 40, 41, 42), according to the number of pieces of timber which are combined to form them. The several pieces are scarphed together, and coaked and bolted, the scarphs being always vertical. Hooked scarphs, with keys of hard wood or iron driven in, to bring the buts in close contact, have been lately introduced with much advantage in great additional neatness of appearance, great reduction of weight, and consequently of materials and expense, by Mr Edye, the master-shipwright of Pembroke yard, fig. 38.

Iron applied to ship-building.

It is rather surprising, that in the very general application of iron for ship-building, the wooden beams which occupy so much space between deck and deck, and so materially contribute to the height of the vessel above the water, have not either been superseded by beams of iron, or at least by wood beams of much less moulding, to which the necessary rigidity might be given by iron plates at their sides. An objection to beams wholly of iron would arise from the great expansion and contraction of that metal under variations in its temperature.

The beams of ships are supported at each end, and the strain to which they are subjected is a downward pressure; consequently the upper part of the beam must compress, and the lower fibre elongate, before there can be any alteration in the curvature. It is desirable therefore that the fibre of the wood towards the lower part of the beam should not be wounded, and that, whether for the purpose of securing the beam, or of security to the beam, no incision should be made, excepting in the upper, or compressed, ranges of the fibre, which may be cut through, according to Du Hamel's experiments, one half, and according to Professor Barlow's, five eighths, of their depth, without impairing the strength. Nay, if the carling or material to be inserted in the score be of harder texture than that which is removed, the strength is increased.

Connexion of beam-ends to ship's side.

The connexion of the ends of the beams to the sides of the ship has afforded scope for the display of much ingenuity. We have in our plates (CCCCLV. and CCCCLVIII.) given sketches of those plans which have been adopted in the navy of England, and also of several taken from foreign works or observed in foreign yards. There are three things to be considered in the connexion of the beam with the side: that it shall act as a shore to prevent the sides from collapsing; as a tie to prevent their falling apart; and be perfectly rigid, that there may be no working.

That the beam may be an effective shore, nothing more is necessary than that the abutment of the end against the ship's side may be perfect. In order to constitute it a tie between the two sides, it is generally dowelled to the upper surface of the shelf, and the under surface of the water-way is dowelled to it. These dowels connect it therefore with the fastenings of the shelf and water-way, which pass through the side. There is also in the ships of the royal navy a plank called a side-binding strake, scored down over and into the beam-ends, at some distance from the side, and bolted through the side between the beams. The scoring into the beams connects the in and out fastening of this strake with the longitudinal tie of the beam. There are also the various bolts forming that part of the fastening of the beam-ends, whether in the knees or in the chocks, which passes in and out through the ship's side.

It will be very easily conceived, from the short outline which we gave of the disturbing forces acting on a ship, that the strain on the ends of the beams to destroy the rigidity of their connexion with the side must be very great when the ship is under sail either on a wind or before it, that is, either inclined or rolling.

Forces to which they are subjected.

The principal action of these forces is to alter the vertical angles made by the beam and the ship's side; and it will be seen that the action is alternately to decrease and to increase the angles made by the beam and the part of the side below it, or, what is the same thing, alternately to increase and decrease the angles made by the beam and the ship's side above it. Now the first of these actions takes place on the lee side; the gravitation of the weather side, and all connected with it, of the deck and every thing upon it, as well as the upward pressure of the water, all tend to diminish the angle made by the beam and the ship's side below it, and increase the angle made between them above it. The contrary effect is produced on the weather side, the angle above the beam being closed, and that below opened.

Beams considered as levers.

In investigating the nature of the action of these forces, we shall find that in each case the beam may be considered as a lever. The power being supposed to be applied at the opposite end of the beam to that at which the forces under investigation act, the weight being the fastening applied to prevent alteration in the angle formed by the beam and the ship's side, and its action being supposed to take place at the point in which it should be applied to produce the most advantageous effect.

Effect on lee-beam arm.

On weather-beam arm.

The lever is of the first order, that is, with the power and weight on opposite sides of the centre of motion or fulcrum, when its effect on the lee arm is considered; and it is of the second order, that is, with the power and weight on the same side of the fulcrum, when its effect on the weather arm is considered.

The object in securing the beam-ends in each case should be to diminish the effect of the power and increase that of the weight. We lessen the effect of the power by diminishing the distance between the point at which it acts and the fulcrum, and we increase the effect of the weight by increasing the distance between the point at which it acts and the fulcrum. In the lever of the first order, that is, when we are considering the action on the lee arm, this is accomplished by bringing the support of the under side of the beam, the midship side of which support is the fulcrum of the lever, as far from the ship's side as it can be extended consistently with the accommodation of the decks; and by having the weight, that is, the security to keep down the beam-end, as close to the end of the beam, and consequently to the ship's side, as it can be placed.

In the lever of the second order, that is, when we are considering the action on the weather arm, the effect of the power is diminished by increasing the distance between the fulcrum and the weight. The fulcrum, in this case, is the support of the lower side of the extreme end of the beam; the weight is the strength of the knee, or whatever connexion is intended to tie it to the ship's side, and maintain the angle invariable which is formed by them. The effect of this weight is increased by approaching it to the point at which the power is supposed to act. Therefore, in order to resist the action on the weather arm of the beam, the fulcrum, which, as we have said, is the support of the extreme end of the beam, that is, the edge of the clamp or shelf which fays to the timbers, should be most firmly connected to them; and the weight, which is the downward tie, should be extended as far from the side as it may be consistently.

The difference of the action to which the two arms are subjected, points out therefore at once the principle which should guide us in all plans for connecting the beams to the side, and it may not be useless to recapitulate our conclusions.

The action on the lee arm requires the extreme end of the beam to be closely tied down, either to the clamp or the shelf, as the case may be, and which is necessarily presumed to be firmly connected to the ship's side. This action also requires the centre of motion to be extended far from the side, in order to diminish the effect of the power. Therefore, the downward fastening close to the ship's side, and the upward support far removed from it, is that which is necessary in this case.

The action on the weather arm requires an exactly different disposition of the securities. The extreme end of the beam is here the centre of motion, and is the part which ought to be supported; and it is the downward tie which should be as far extended from the side as may be consistently.

It may be urged against these views, first, that if working be presumed to take place in the lee-beam arm, round the midship or outer edge of the shelf, the distance between this fulcrum and the fastenings which keep the beam-end down will cause greater motion in that end, and greater strain on the fastening; and, secondly, that if the weather-beam arm be presumed to work from the side or inner edge of the clamp or shelf, the distance between this point and the fastening intended to keep the beam down, will cause an increased strain on that fastening.

These objections are both true, but they do not embrace the correct view to be taken. The object is how to dispose the fastenings in the best possible manner, in order to prevent working. And this is attained in each case by extending the distance between the weight and the fulcrum.

Shelf and clamp as securities of the beam-end.

In the system of building the ships of the royal navy, introduced by Sir Robert Seppings, the shelf was brought upon the clamp (*m*, Plate CCCCLV.); it is now worked home to the timbers (*i*, *k*, *l*), and its front is therefore less extended from the side. One joint, that between the clamp and shelf, is avoided by this method, but security to the beam-end is lost by it. An arm of the iron knee, which has superseded Sir Robert Seppings' forked knee, is extended under the beam to compensate for this diminution in the width of the shelf; but unless the rigidity of this arm be such that the fulcrum in the case of the lee-beam arm, and the weight in the case of the weather-beam arm, be removed from the ship's side a distance at least equal to the diminution in the extension of the front of the shelf from the ship's side, the object is not attained.

Plate-bolt.

Strap.

One of the most perfect securities for a beam-end, in point of principle, and combining at the same time simplicity of workmanship, which is another important requisite, especially in all iron work, is the plate-bolt (*a*), frequently adapted for round-house beams, and for the lower decks of frigates. The extreme end of the beam is tied downward by bolts, and supported by the shelf, and the extended downward fastening is by a dog-plate. These securities, and the upward support afforded by the chock to that plate, are, according to the foregoing reasoning, correctly applied, but are insufficient in amount of security for the beams of principal decks, as the downward tie depends wholly on the clench of the dog-plate. Probably a strap passing round the beam, as shown in fig. 44, Plate CCCCLVIII., might be an advantageous and simple modification of the above plan. For easiness of execution, and smallness of expense, it would be better if the strap was merely bent over, and scored into the top part of the beam, and the ends brought down and fastened on the sides of the chock, which would then require to be only of the same siding as the beam. In this case there could be no in and out fastening through the strap; the only in and out bolts would be those through the chock. The fastenings of the strap might be screws, as in the French knees (Plate CCCCLVIII. figs. 45, 46), which we shall describe. The disadvantage attending this sort of strap would be, that to obtain an equal degree of downward security for the weather-beam arm, the chock must be more extended from the ship's side than if the ends of the strap were brought in front of the chock, and took their own in and out fastening.

Advantages of the chocks.

The extension of the security from the side of the ship by means of a chock, is preferable to gaining the same breadth by bringing a shelf on to the clamp with a chock under it, in so far as extending the support to the beam is involved; because the chock presents "end-grain," in which there is comparatively but little shrinkage, to receive the downward pressure of the weather-beam arm. A well secured and firmly supported clamp is sufficient to resist the downward pressure of the weather-beam arm; and if this clamp be of a sufficient thickness to receive the up and down bolts through the water-ways and beam-end, that is all that is indispensable, and this would be little, if any, addition to the thickness of clamp already usually worked. We therefore doubt much whether the shelf might not be advantageously discontinued, and substituted by a clamp with chocks under the beams, stepping on the projecting edge of the spirketing. We shall speak of the support to this clamp when we consider the short stuff between the ports. Of course this change presupposes a maximum of advantage to be derived from all the other combinations for strengthening the side.

Objections to chocks.

An objection is urged against chocks, which is, that they occupy space against the ship's side; but they afford a security to the beam-ends which cannot be well obtained without them; and it is questionable whether the foundation of the objection is correct, because the continuous breadth of shelf should also be considered, and that effectually prevents a man's standing erect close to the ship's side, while the obstruction from the chocks is only partial, with intervals between.

Roberts' plate-knee.

Roberts' plate-knee (*d*, Plate CCCCLV.) is a very strong method of fastening, as a preventive to any alteration of the angle formed by the beam and the side, provided the in and out security of the chock to the side is sufficient to resist the strain that is brought on it. These knee-plates, together with up and down bolts in the beam-ends, fulfil all the requisites for a correct mode of fastening, unless it may be the objection against the chock which we have stated. The great objection which has been urged to their use arises from the fore and aft bolts through the beam, which, it is said, are liable to split the beam-end.

All fore and aft bolts through the beam-end, as they do not pass through the fulcrum round which the beam would work, are nearly equally liable to this objection, whether they occur in the same range of fibre or not, because when motion ensues they must all act to split the beam-end. But we have already said we do not consider this line of argument should be urged. The occurrence of working should not be presupposed in determining securities to prevent it, because such a course would frequently militate against the application of the most advantageously disposed preventives to motion; not however that we are arguing in favour of fore and aft bolts through beam-ends ranking among these; on the contrary, we think they should be avoided.

The foregoing observations embrace the main outline of the principles which should be kept in view in connecting the two sides of the ship by means of the beams.

Hooks.

The bows, as we have already said, are connected by timbers called hooks. It is important to remember that the hooks above and those below the surface of the water are subjected to an opposite strain. The tendency of the pressure of the water on the bow is to make the sides collapse, and therefore the hooks below the water's surface should not only act as ties to the bow while the ship is grounded, as, for instance, when in dock, but should be formed more especially to resist the pressure of the water when she is afloat. Those hooks which are above the surface of the water act principally as ties, the rake of the bow and the gravitation of its parts tending to separate the two sides of the ship. These observations are of little importance when the hooks are of wood; but when they are formed partly of wood and partly of iron, they materially affect the application of the iron plate. Below water it should evidently be brought as close to the inner surface of the bows as possible, and therefore on the fore side of the hook. It should also be secured to the wooden ekeings, independently of the bolts which secure the hook to the bows. Very slight consideration will suffice to prove, that by these means the utmost advantage is obtained from the materials employed, to resist the pressure, while at the same time they form a sufficient tie to support the sides of the bows when the ship is in dock, before launching, or aground. In made hooks above the water, the iron plate should be on the aft side, as far from the bow, and as straight as may be, that it may be a more effective tie.

We shall now pass to the several systems of strengthening the sides, and of preventing the hogging, which have been successively introduced.

In the system of building which was superseded by that termed the diagonal system, the whole of the interior surface of the frame was planked, and a series of internal frames worked upon this planking, agreeing in direction with the timbers of the ship (Plate CCCCLVI. fig. 47). They appear principally to have been intended to support the frame in the event of the ship's grounding, as they could add no longitudinal strength to the fabric. There were about eight "bends" of the "riders" in three-decked ships, and six bends in two-deckers. There were other timbers running up to the top-sides, called breadth, middle, and top riders. These were more closely spaced than the bends in the lower parts of the body, and were placed in a diagonal direction evidently only to avoid the ports. The beams were secured to the side by hanging and lodging knees of wood: they rested on the clamp, there being no shelf. The water-way was merely a thicker strake of deck gouged out, or "chined down," as it is technically called, from the front of the spirketing, to the same thickness as the flat of the deck. This chining down is for the protection of the water-way seam, by keeping it above the run of the water. There were different methods of shifting the bends of riders in the hold, several of which we have introduced in the plate.

Vertical riders.

An enormous quantity of timber was thus massed together, having the appearance of great strength; but in fact, from its weight, injudicious combination, disposition, and fastening, much of it was, if not injurious, at least useless. The riders in the hold were no doubt originally necessarily introduced when ships were "grounded" for repairs; but that necessity has now ceased to exist. In the earliest drawings representing them there are "pointers," or shores, extending from them at the bilge of one side, to the gun-deck at the opposite side of the middle line, which we shall presently refer to.

The system we have described was partially superseded by single riders in the hold, scarphing to chocks under the orlop-beams, and running down to give shift to the floor-heads. The top-sides were supported by standard knees brought on the deck over the beams; and the beams were secured by Roberts' plate-knees brought on the sides of chocks under the beams.

The idea of diagonal trussing was not novel at the time the system of Sir Robert Seppings was first proposed: It may even be observed in Plate CCCCXLVI. in the vessel of the fifteenth century, under repair. In the plates of a Dutch work of the date of 1697, there are diagonal pointers in an athwartship direction from the floor-heads on one side, to the quarters of the upper-deck beam of a two-decker on the other. Sir Walter Raleigh also mentions this mode of strengthening ships; and the Dutch author, Van Yk, gives the drawing as a representation of the English system of building at the date of the publication of his work. Somewhat similar also were those afterwards proposed by Mr Snodgrass, the surveyor of shipping to the East India Company, though his were to step upon the keelson and extend to the clamps of the lowest gun-deck, and were therefore less judiciously placed to resist the strain in grounding than those represented in the Dutch work. Diagonal trussing between the keelson and the gun-deck beams along the vertical longitudinal section of the ship, had also been proposed, and partial experiments of various diagonal supports or shores made, both abroad and in England; but until the introduction of the diagonal riders and trusses by Sir Robert Seppings, there had been no permanent results from these experiments.

We quote the following description of the system from a paper communicated by the inventor to the Royal Society, and which is printed in the Philosophical Transactions for 1814.

Diagonal frame.

"An accurate conception of the state of a ship's hold may be formed by referring to the longitudinal section (fig. 48), which is termed the Jesuit's perspective, or bird's-eye view of the internal part of one side of a seventy-four-gun ship in a complete state, with fillings in the openings between the timbers of the frames, instead of the planking over them.

"In this state the diagonal timbers are introduced, intersecting the timbers of the frame at about the angle of forty-five degrees, and so disposed as that the direction in the fore is contrary to that in the after part of the ship (as may be seen in the engraving), and their distance asunder from six to seven feet or more; their upper ends abutting against the horizontal hoop or shelf-piece of the gun-deck beams, and the lower ends against the limber strakes, except in the midships, where they come against two pieces of timber placed on each side of the keelson (called additional keelsons), for the purpose of taking off the partial pressure of the main-mast, which always causes a sagging down of the keel, and sometimes to an alarming degree. These pieces of timber are nearly as square as the keelson, and fixed at such a distance from it, that the main step may rest upon them. They may be of oak or pitch-pine, and as long as can be conveniently procured. Pieces of timber are next placed in a fore and aft direction, over the joints of the frame-timbers, at the floor and first futtock-heads; their ends in close contact with, and coaked or dowelled to, the sides of the diagonal timbers. In this state the frame-work in the hold presents various compartments, each representing the figure of a rhomboid.

"A truss-timber is then introduced into each rhomboid, with an inclination opposite to that of the diagonal timbers, thereby dividing it into two parts. The truss-pieces so introduced into the rhomboid, are to the diagonal frame what the key-stone is to the arch; for no weight or pressure on the fabric can alter its position in a longitudinal direction, till compression takes place at the abutments, and extension of the various ties.

"This arch-like property of the diagonal frame not only opposes an alteration of position in a longitudinal direction, but also resists external pressure on the bottom, either from grounding or any other cause, because no impression can be made in its figure in these directions, without forcing the several parts of which it is composed into a shorter space.

"The beams are disposed in the new system nearly as usual, except that in midships, where a ship necessarily requires the greatest security, two additional beams have been introduced.

"The beams of the several decks are attached to the ship's side in the following manner.

"*1st*, By shelf-pieces or internal hoops, distinguished by the letter E. These shelf-pieces are composed of several lengths of timber, scarphed or joined together by coaks or circular dowels, so as to form a kind of internal hoop, extending from the hooks forward, to the transoms abaft—(in the plate the transoms are not shown, as we have chosen the perfected application of Sir Robert Seppings' system, after the adoption of the circular stern into the service),—to the under side of which, as well as the under parts of the beams, they are securely coaked, and being then firmly bolted to the side, instead of becoming a mere local fixture of the beam to the ship's exterior frame, as knees were, they are one continued and general security. The shelf-piece is also a tie to the top-side in a fore and aft direction, co-operating with the trussed frame, as already explained.

"*2dly*, By chocks, represented in Plate CCCCLV. (*m*, *o*), which are placed under all the shelf-pieces in wake of the beams, except the orlop, in such a manner as to receive the up and down arm of the iron knees. The lower ends of those under the gun-deck shelf-piece step on the ends of the orlop-beams; and those of the several decks above, step on the projecting part of the spirketing below. The chocks, particularly those between the orlop and gun decks, admit of their being driven into their respective places very tightly, thereby acting like pillars. Another advantage attending them is their great tendency to stiffen the ship's side, and to prevent the beam-ends from playing on the fastenings when the ship is rolling, or straining under a press of sail.

"The curved iron-plate knees for securing the orlop-beams, and the iron forked knees of the other decks, are described in (*n*) and (*m*), Plate CCCCLV.

"The tendency of the ship to stretch or draw asunder in her upper works being by no means obviated by the short planks on the inside between the ports, a truss piece of plank is substituted in lieu of them, which being well secured at the abutments, very materially aids the trussed frame, and gives great stiffness, thereby opposing the inclination to arch or hog aloft."

These various alterations from the old system of building had the effect of very greatly increasing the strength of the ships of the royal navy. Among so many changes, it is not improbable that erroneous conclusions may have been drawn as to the relative importance of each. We incline much to the opinion that this has been the case to a very great degree, and that a part hitherto considered as quite subordinate, and now wholly discontinued as useless, was one principal cause of the increase of strength which enabled ships to preserve their sheer. This we shall presently endeavour to prove.

The diagonal frame.

The lower ranges of riders and trusses, which were brought on the upper surfaces of the floors and first futtocks, could have but little effect in preventing arching beyond that which arose from the additional resistance they offered to compression, and the additional rigidity they gave to the structure in the event of grounding, or of being ashore. They certainly served as a firm base upon which to erect a series of riders with diagonal trusses, which were more advantageously placed to afford efficient support to the extremities of the body. Yet these upper riders only extended to the securities of the gun-deck, and therefore not very far above the line of non-action. Presuming, however, that this second series of riders was of considerable utility, a firm base for them might probably have been obtained without so much incumbrance to the hold, and consequently without the objection being urged against it, which was made to the diagonal riders, of diminishing the stowage. According to the estimates made by Sir Robert Seppings, the actual cubical contents of the diagonal frame were less than those of the ceiling which it superseded.

Trussing between the ports.

The trussing between the ports has been discontinued in Her Majesty's ships. We cannot but regret the change, as we consider this was the most advantageous innovation connected with the diagonal system, and one in which the benefit was unaccompanied with compensating inconveniences.

In investigating the reasons on which we found this opinion, we shall merely describe the manner in which we consider this trussing must have acted, to prevent any alteration of form in the upper parts of the ship.

We commence, then, with the gun-deck of a three-decker. The gun-deck, from its proximity to the line of inaction, from the support of the trussed frame, which extended to its shelf, and from the wales, may be assumed, at least in a new ship, as a most firm base on which to raise a series of supports. At some point on the upper edge of the gun-deck spirketing, a shore, that is, the truss, firmly cleated at its heel, extended upwards and aft, in the after-body of the ship, to the lower edge of the middle-deck clamp, where it was securely cleated; immediately above the head of this shore a second was fixed on the upper edge of the middle-deck spirketing, and extended upwards to the lower edge of the main-deck clamp, where it was secured; and immediately over the head of this shore a third was secured, on the edge of the main-deck spirketing, and extended upwards to the lower edge of the quarter-deck clamp, where it was finally secured: so that a point in the range of securities to the quarter-deck was continuously and firmly shored up from a point in the most rigid and unalterable part of the ship; and, in the same manner, a series of points along the range of securities to the quarter-deck became shored up from the same foundation. This is in the after-body. In the fore-body a corresponding system of shoring ran in an opposite direction forward, and in a similar manner supported the range of securities of the forecastle, while each intervening deck partook of the same advantage.

Radiating as these shores did in opposite directions from the most rigid part of the ship as their base, while they afforded a series of points of support to the principal longitudinal ties, they formed with them a system of triangles; and the triangle is a figure which admits of no alteration of form; for as long as the sides remain the same, the angles are invariable. It might almost be said to be impossible, therefore, for the range of quarter-deck and forecastle securities, by which we mean the clamp, shelf, and water-way, to drop at the extremities, excepting in so far as the compressibility of the materials would admit.

To adapt another, and perhaps a stronger, view of this system of trussing, we may consider the whole top-sides of a ship, with the securities of the gun-deck as a base, to be a series of horizontal ranges of materials, supported by alternations of firmly secured triangles, so placed, that the bases of the superior ranges of these triangles derive firm support from the triangles of the inferior ranges. Considering the unalterability of form of the triangle, and the advantage of the pressure being brought upon the end grain, in which there is comparatively little shrinkage, this is certainly a mode of constructing a top-side which must be possessed of great rigidity. In fact, if there was an error in the system of trussing the top-sides adopted by Sir Robert Seppings, it was, that he did not extend it to the extremities, even round the bow and stern, and also apply a similar system to the short stuff outside between the ports.

The advantages to be derived from triangular combinations of the timber composing the hull of a ship are yet but imperfectly appreciated. We have no doubt that great improvement in ship-building is to be effected by these means, unless, indeed, timber should be superseded by iron, and the stupendous and costly line-of-battle ship be destined to give place to small but powerfully armed steam-boats. An iron sailing vessel is being built in Scotland, of between five and six hundred tons burthen. It seems also not improbable that the introduction of so destructive a missile as the hollow shot into naval warfare, will render it expedient to diminish the aggregate loss from their effect, by lessening the size and increasing the number of the vessels used in naval battles. This is, however, as yet merely speculative.

Filling in the openings.

Another important part of the diagonal system, as it is described in the foregoing account given by Sir Robert Seppings, was the making the bottom a solid mass, by filling in the openings between the frame-timbers. This we have already mentioned as most effective in resisting alteration in form. It possessed a more important advantage, in the immense additional safety it assured to the vessel in the event of grounding, or of starting a but of the plank. The introduction of the system of solid bottoms into the mercantile navy, which Mr Ballingall has so long and so strenuously urged, would be an incalculable advantage, not to the merchant or ship-owner, for the system of insurance is their refuge, but to a class of men of equal value to England with either merchant or ship-owner—seamen, whose lives are often most cruelly sacrificed to the present immunity from pecuniary loss which marine insurance guarantees to their employers.

We are no friends to the system of marine insurance. We doubt much whether the evils which have resulted from it, in the loss of human life, and its attendant miseries to survivors, the system of gambling which it encourages among all classes of commercial men engaged in it, and the fraud and crime which it often occasions, do not more than counterbalance its advantages, which, after all, may be summed up in this, that in the event of shipwreck, the merchant and ship-owner are indemnified for a loss which, in a majority of cases, would not have occurred had it not been for the recklessness and carelessness engendered by the very knowledge that this indemnification was to be purchased. We here advance no unsupported opinion: the Report of the committee of the House of Commons on shipwrecks says, "The system of marine insurance, though affording the means of protecting individuals from excessive loss, has nevertheless a tendency, by transferring the pecuniary responsibility for such losses from the owners of ships to the underwriter who insures them, to induce less care in the construction of ships, less efficiency in their equipment, and less security for their adequate management at sea; in as much as the risk of such loss to the ship-owners can be covered by a fixed premium of insurance, which, being charged on the freight, and then recharged on the goods conveyed, fixes the real responsibility and real loss ultimately on the public; as all the parties actually engaged in the transaction can insure themselves from any participation in such loss, by the aid of marine insurance." This, too, is from the Report of a committee composed principally of merchants, of ship-owners, and of ship-builders. But to return to our more immediate subject, though we can hardly call this a digression, connected as it is with the progress of the science we are writing on.

Modern diagonal supports, and system of building.

The system of wooden riders, longitudinal pieces, and trusses (Plate CCCCLVI. fig. 48), is now discontinued in Her Majesty's ships, and is superseded by a modification of the iron riders or braces, which were formerly only proposed by Sir Robert Seppings for frigates and the smaller classes of vessels. In the recent adaptation of these braces to line-of-battle ships, there are several material differences from the original plan. The ceiling, with its thick strakes over the heads and heels of the timbers, is restored, excepting that the planking between these thick strakes is laid diagonally, as shown in Plate CCCCLVII. fig. 49. There are also two ranges of iron riders; the lower range is brought upon the inside of the timbers of the frame, and the ceiling worked upon and scored over them. The upper ends of this range of riders extend forward in the fore-body and aft in the after-body, and the heads run high enough to turn out upon the orlop clamps, and bolt through them. The riders of the upper range give long shift to those of the lower range, and their direction crosses that of the lower range at right angles. Both ranges are very securely bolted through the bottom.

It will have been evident from the foregoing remarks, that we do not consider the hold as an advantageous situation for any great expenditure, either of workmanship or materials, simply for the purpose of preventing the alteration in the form of a ship.

After having obtained the greatest degree of incompressibility compatible with the materials used, the next object, in this part of the body, should be to insure adequate local strength to resist the strain of taking the ground; and we assume it for granted, that it is for this purpose the thick strakes at the heads and heels of the timbers have been restored, and also that the lower tier of iron riders is worked. The placing the ceiling diagonally between the several assemblages of thick strakes, was probably with an idea that it would act as a trussing; but, according to the views of the action of the disturbing forces which we have taken in this part of our article, it can have little, if any, effect in preventing alteration in form, beyond that of ceiling worked in the ordinary and less costly manner, and is inferior in other respects.

In the upper range of riders the iron bars are placed with their upper ends extending inwards from the extremities of the ship, offering a series of very effective ties, or braces, to connect the unsupported extremities of the vessel to the midship, or supported part, and to the firm basis of the zone about the surface of the water. This series of braces is unquestionably advantageous, and is also correct in principle, as affording support to the extremities of the vessel, by connecting them with the most unalterable part of the fabric, and to that portion which is abundantly supported by the external fluid. We think it probable that the additional strength resulting to the lower part of the vessel from the lower range is scarcely adequate to the additional expense incurred by working them, with all the accessory fastening and fitting. This method which we have described of strengthening the floor, has not near the rigidity to resist damage from grounding, of the system that it has superseded, which certainly did, according to the intention of the inventor, partake of the nature of an inverted arch, or rather dome. It has, however, one, and that too a very considerable advantage, over the wooden diagonal system, as it offers a fair surface for stowage.

The system of iron diagonal riders which we have described is that adopted in line-of-battle ships. There are several variations from this system, in its adaptation to the smaller classes of vessels. The general features are however the same. The modifications all tend more or less to simplify it in its details. There are, however, some instances in which the iron bars have their upper ends extending outwards, towards the extremities of the vessel, probably in order to assimilate them to trusses; but this is evidently, next to the vertical, the least advantageous position they could be placed in.

Stern.

Of all the modern innovations in ship-building, the alteration from the square termination to the round in the sterns of ships was received with most general reluctance, so wedded is the eye to the forms it has been habituated to gaze upon; yet it may be fairly questioned whether, if cannon had been used for naval warfare when ships were first built, a square stern would have ever been constructed, and also whether the curvilinear termination to a body, every outline of which presents curves to the eye, is not more consistent with the requirements of a correct taste. Be these questions answered as they may, it is certain that the alteration was attended with a great local increase of strength in a part which had always previously been considered the most imperfectly combined in the whole hull. This was in consequence of the various changes in the timbering which were required to maintain the angles in the contour of the square stern. (Plate CCCCLIX.) First, the ends of the transoms were very insecurely connected with the sides of the ship; then the connexion between the counter-timbers and the transoms was equally insecure; and, lastly, the planking along the sides had no connexion with, and consequently formed no tie to, that on the stern. In the round stern, the timbers of the frame continue to give shift to each other, and to be firmly connected together all round the curve of the stern; the various internal supports are uninterrupted; and the principal planking, being continued from side to side, binds the whole together, and makes the stern little inferior to the broadside in local strength.

Circular stern.

The object for which the circular stern was introduced was not so much increased strength in mechanical structure, as increased strength in defence from attack. Most of the modifications of the round stern which have been introduced to preserve the appearance of the square form, and yet obtain the same increase of means of defence or of aggression, have been considerable improvements in point of mechanical construction on the old square stern, but they are certainly inferior to the circular stern in strength. This is partly in consequence of the great rake given to them, which also diminishes the advantage that was the object of the original alteration; the increase of the means of attack or defence, as the explosion from the muzzle of the gun will scarcely clear the ship's side.

The great extent to which this rake is now carried is exemplified by comparing the rake of the stern of the Queen, an English first-rate, which is three feet nine inches in ten feet, with the rake of the stern of the Achille, a French line-of-battle ship, which is only two feet two inches in ten feet. We quite grant the beauty of appearance arising from the rake of the stern; but beauty of appearance is not an essential for a ship of war. In fact, we believe that the stern adapted for a ship of war is yet to be designed, and that sterns will eventually be towers of strength, nearly vertical from the counter to the taffrail.

The three modifications of ships' sterns of which we have been speaking will perhaps be more clearly understood by an examination of Plate CCCCLIX.

Bows.

The drawings (Plate CCCCL.) which we have selected for exemplifying the various plans, sections, and lines connected with the draught and the laying off, are those of the Vindictive, a frigate having an important improvement in the form of the bow above water, introduced by Mr Blake, the master-shipwright of Portsmouth yard, by which her battery for chase is very considerably increased in strength and efficiency. These advantages are gained without the loss of any strength, and without the addition of cost, in building; so that it is highly to be desired that this ship should have a fair trial at sea. The stern of this ship is a modification of the circular formed stern, also from the design of the same gentleman.

We shall now proceed to notice some of the peculiarities observable in the French practice of ship-building. The characteristic difference in their system from our own, which would strike an observer accustomed to English ship-building, would evidently be a less expenditure of material.

French ship-building.

The French have retained the old system of frames and filling timbers. Frequently the frames are close jointed throughout their height, and the filling frames put up as single timbers, as is shown in fig. 50, Plate CCCCLVIII. The filling timbers are also frequently of fir. Both frames and filling timbers are chain-bolted. There is no shelf under the beams, only a thick clamp, and a wide chock worked upon the short stuff, and up to the beam (Plate CCCCLVIII. fig. 45). There are generally three side binding strakes faced one inch on, and scored one inch over the beams, and bolted together by in and out bolts passing through the water-way, which is also faced and scored in the same manner. These bolts are secured with nuts and screws at the points, on the outside plank.

Water-way.

The water-way is not always scored over the beams, but is sometimes brought plain on their ends (fig. 46). The bolts of the binding strakes, which are then also merely brought on to the beams, secure its lower edge; and in both cases it has in and out bolts through the ship's side, to secure its upper edge.

Beam-ends.

The method of connecting the beam-ends with the ship's side, which appears to be most generally adopted in the French ships at present, consists of a chock under the beam (fig. 45), securely bolted through the ship's side, the points of the bolts being set up with a nut and screw. The beam-end hooks over the head of this chock. A plate-knee similar in shape to that known in the English service as Roberts' knee is brought on each side against the chock and beam; but these knees, instead of having a short arm against the ship's side for taking in and out fastenings, themselves form the bolt, each knee having an arm which is driven through the side by means of a shoulder worked in the knee, similar to the shoulder of a dog-bolt. The outer end is secured by a nut and screw. The security of the plate-knees to the beam and chock consists only of three screws in each arm, and one screw in the diagonal brace. These screws are not above five inches long. Thus the security of either knee is completely unconnected with that on the opposite side of the beam.

Planking.

The wales, diminishing stuff, and plank of the bottom, are all treenail-fastened, the buts are secured with two bolt-nails in the timber on which the but is placed, and a through-bolt is driven in the timber next the but. In some instances the plank is nail-fastened, but whether with nails or treenails it is double fastened. The treenails are not caulked on the ceiling, but wedged with conical wedges. Most of the principal bolts, as those of the water-ways and chocks, under the beams, are set up outside with a nut and screw; and great care is taken to omit the fastening of the wales and outside planking, wherever these bolts can be advantageously made to answer as fastenings for them.

There is no regular system observed in shifting the buts of the plank, as there is in the English service; but the planks are worked to their full length, without reference to the shift: the only rule which appears to be observed is, that there shall be about two feet shift between the buts of following strakes.

Rather an interesting experiment as to the possibility of diminishing the scantling of the timber, to any great extent, which is used for building large ships, is in progress in the French navy. The Surveillante, a large frigate, was built wholly of small timber, about ten years ago, and as yet the reports on the system are favourable.

The following is an outline of the plan on which she was built.

Small timber.

The keel, stem, and stern-post are formed of various pieces of timber combined as in the section, Plate CCCCLVIII. fig. 51.

The several lengths of the centre piece, or core, are scarphed together, while the side or strengthening pieces only but with plain buts; care being taken that the buts and scarphs give good shift to each other.

There are in this system no other frames than those which form the sides of ports, and the timbers composing these frames are bolted together, without leaving any opening between them, that is, close jointed. The spaces between the frames are filled in with single timbers, or rather with a frame-work of timber fitted together in the manner shown in fig. 52.

The cant-bodies are framed as in the ordinary method, the after-body timbered round to the post without transoms or fashion-pieces.

From the main-deck upwards the scantlings of the frames are not different from those of a ship of a similar size built in the usual manner; but below this line there is a very considerable reduction. This reduction commences at the lower edge of the gun-deck clamps, and there a couple of thick strakes are worked up to the lower edge of these gun-deck clamps, to form an abutment for a series of internal timbers, brought on the inner surface of the timbers of the frame, and crossing them at an angle of 45°, the upper ends being placed forward in the fore-body, and aft in the after-body. These timbers but at their heels on the heads of a series of internal floor-timbers, brought on the upper surfaces of the floors of the frame. These internal floors are laid athwartships. The openings between the timbers of this internal diagonal frame are filled in with wedge-fillings, so that the whole hold presents one smooth surface for stowage.

Wherever there is an athwartship bulk-head, there is a system of riders worked on the inner surface of this diagonal frame, but taking a vertical direction. The timbers of these bends of riders are not wrought side by side, but one series of timbers is worked on the inner surface of the other, and the bolts pass in and out through both, and through the bottom. These riders run up to the lower deck, and a beam is so disposed with respect to each bend of riders, as to be secured to their heads, and form a part of the system. The bulk-heads which necessarily fill in the space between the beam and the riders run diagonally up on either side the middle from a midship pillar to the beam and riders. Each bulk-head is water-tight.

### *On Launching.*

Launching.

Ships are generally built on blocks which are laid at a declivity of about $\frac{5}{8}$ths of an inch to a foot. This is for the facility of launching them. The inclined plane or sliding plank on which they are launched has rather more inclination, or about $\frac{7}{8}$ths of an inch to the foot for large ships, and a slight increase on this for smaller vessels. This inclination will, however, in some measure depend upon the depth of water into which the ship is to be launched.

While a ship is in the progress of being built, her weight is partly supported by her keel on the blocks, and partly by shores. In order to launch her, the weight must be taken off these supports, and transferred to a moveable base; and a platform must be erected for the moveable base to slide on. This platform must not only be laid at the necessary inclination, but must be of sufficient height to enable the ship to be water-borne, and to preserve her from striking the ground when she arrives at the end of the ways.

For this purpose, an inclined plane, *a*, *a* (Plate CCCCLVIII. figs. 53, 54), purposely left unplaned to diminish the adhesion, is laid on each side the keel, and at about one sixth the breadth of the vessel distant from it, and firmly secured on blocks fastened in the slipway. This inclined plane is called the sliding plank. A long timber, called a bilgeway, *b*, *b*, with a smooth under surface, is laid upon this plane; and upon this timber, as a base, a temporary frame-work of shores, *c*, *c*, called "poppets," is erected to reach from the bilgeway to the ship. The upper part of this frame-work abuts against a plank, *d*, temporarily fastened to the bottom of the ship, and firmly cleated by cleats, *e*, *e*, also temporarily secured to the bottom. When it is all in place, and the sliding-plank and under side of the bilgeway finally greased with tallow, soft soap, and oil, the whole framing is set close up to the bottom, and down on the sliding plank, by wedges, *f*, *f*, technically called slivers, by which means the ship's weight is brought upon the "launch."

When the launch is thus fitted, the ship may be said to have three keels, two of which are temporary, and are secured under her bilge. In consequence of this width of support, all the shores may safely be taken away. This being done, the blocks on which the ship was built, excepting a few, according to the size of the ship, under the foremost end of the keel, are gradually taken from under her as the tide rises, and her weight is then transferred to the two temporary keels, or the launch; the bottom of which launch is formed by the bilgeways, resting on well-greased inclined planes. The only preventive now to the launching of the ship is a short shore, called a dog-shore (*g*), on each side, with its heel firmly cleated on the immoveable platform or sliding plank, and its head abutting against a cleat (*h*), secured to the bilgeway, or base of the moveable part of the launch. Consequently, when this shore is removed, the weight of the ship forces her down the inclined plane to the water. To prevent her running out of her straight course, two ribbands are secured on the sliding plank, and strongly shored. Should the ship not move when the dog-shore is knocked down, the blocks remaining under the fore part of her keel must be consecutively removed, until her weight overcomes the adhesion, or until the action of a screw against her fore foot forces her off.

French method of launching.

Fig. 55 (Plate CCCCLIII.) will give an idea of a method of fitting the launch which is practised in the French yards. It must be observed, that the plan requires a firm foundation to the slipway, and therefore it is not generally applicable.

The two pieces (*a*, *a*) which are shown in the figure as being secured to the ship's bottom, are the only pieces which need be prepared for each ship; the whole of the remainder will be available for every launch. These pieces were, in the launch fitted to the bottom of a fifty-gun frigate, seven inches thick on their outer edges at the midship bend, and were in length one third that of the ship.

A space scarcely more than half an inch was left between them and the baulk-timber, which was placed beneath them (*b*, *b*), as it was not intended that the ship should bear on these baulk-timbers in launching; they are only to support her in the event of her heeling over. The ship was intended to launch wholly on the sliding plank (*c*), which was fitted under the keel. This sliding plank was, in the case in question, about four inches thick. The groundways were of baulk-timber, laid about four feet apart, extending across the slip; between these groundways stacks of blocks were built, so that the sliding plank was supported along its whole length with scarcely greater intervals than about fifteen inches between the supports. The slip was cut from out of the solid rock.

**Launching without subsequent docking.**

Fig. 56 (Plate CCCCLIII.) represents a section of a method of launching a ship which has been coppered on the slip, and which therefore need not be afterwards docked for that purpose. This method of fitting the launch avoids the necessity of docking to remove the launch, by not having any part secured to the ship. The two sides of the cradle are prevented from being forced apart when the weight of the ship is brought on them, by chains passing under the keel. Each portion of frame-work composing the launch has two of these chains attached to it, and brought under the keel to a bolt *a*, which passes slackly through one of the poppets, and is secured by a strong fore-lock *b*, with an iron handle *c* reaching to the ports, at which, when the ship is afloat, it may be drawn out of the bolt; the chain then draws the bolt *a*, and in falling trips the cradle from under the bottom. There should be at least two chains on each side secured to the fore-poppets, two on each side to the after-poppets, and two on each side to the stopping-up (fig. 54); and this is only for the launch of a small ship. The number will necessarily increase with the weight of the vessel.

**Experiments on fastenings.**

We close this article with some most valuable tables of experiments. The first is compiled from one in Moseley's Illustrations of Mechanics, the other three we have been kindly favoured with by Mr Parsons, a member of the late School of Naval Architecture, and formerly belonging to Her Majesty's dock-yard service. These experiments, with a number of others on various securities, were most carefully made by this gentleman; and we regret much that he has not yet made them public to the world, as we are not aware of any similar information being accessible to naval architects or to engineers.

" *Table of the Tenacities of different Substances, and the Resistances which they oppose to direct Compression.*

| Substances Experimented on. | Tenacity, in Tons, per Square Inch. | Name of the Experimenter. | Crushing Force, in Tons, per Square Inch. | Name of the Experimenter. |
|---|---|---|---|---|
| Wrought iron, | | | | |
| in bars, Russian (mean) | 27 | Lamé. | | |
| — English (mean) | 25½ | — | | |
| — hammered | 30 | Brunel. | | |
| rolled in sheets and cut lengthways | 14 | Mitis. | | |
| ditto cut crosswise | 18 | — | | |
| Cast iron, quality No. 1 | 6 to 7¾ | Hodgkinson. | 38 to 41 | Hodgkinson. |
| — — No. 2 | 6 to 8 | — | 37 to 48 | — |
| — — No. 3* | 8 to 9¾ | — | 51 to 65 | — |
| Copper, cast | 8½ | Rennie. | 52 | Rennie. |
| — hammered | 15 | — | 46 | — |
| — sheet | 21 | Kingston. | | |
| — wire | 27½ | — | | |
| Ash, specific gravity, ·6 | 6 | Barlow. | | |
| Teak, — ·9 | 7 | — | | |
| Oak, — ·92 | 5 | — | 1·7 | — |
| Oak, — ·77 | 4 | — | | |
| Fir, — ·6 | 5 | — | | |
| Mahogany, — ·637 | 3¾ | — | | |
| Elm | 6 | | ·57 | — |
| Pine, American | 6 | | ·73 | — |
| Deal, white | 6 | | ·86 | — |

* "The strongest quality of cast iron is a Scotch iron known as the Devon hot-blast, No. 3; its tenacity is 9¾ tons per square inch, and its resistance to compression 65 tons."

" *Table of the Adhesion of Iron and Copper Bolts driven into sound Oak with the usual Drift,† not clenched, and subjected to a direct Strain, as in fig. 57.*

| Diameter of the Bolt. | Number of the Experiment. | Iron. | | | | Copper. | | | | Diameter of the Bolt. | Number of the Experiment. | Iron. | | | | Copper. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Length of the Bolt driven into the Wood. | | | | | | | | | | Length of the Bolt driven into the Wood. | | | | | | | |
| | | Four Inches. | | Six Inches. | | Four Inches. | | Six Inches. | | | | Four Inches. | | Six Inches. | | Four Inches. | | Six Inches. | |
| Inches. | | Tons. | Cwt. | Tons. | Cwt. | Tons. | Cwt. | Tons. | Cwt. | Inches. | | Tons. | Cwt. | Tons. | Cwt. | Tons. | Cwt. | Tons. | Cwt. |
| ¼... | 1 | 1 | 13 | ... | | 0 | 18½ | ... | | ¾... | 1 | 3 | 3 | 6 | 0 | 3 | 10 | 5 | 5 |
| | 2 | 2 | 0 | ... | | 0 | 18 | ... | | | 2 | 3 | 2 | 6 | 0 | 3 | 10 | 5 | 5 |
| | 3 | 2 | 2 | ... | | 0 | 19 | ... | | | 3 | 3 | 10 | 5 | 0 | 3 | 10 | 5 | 8 |
| | 4 | 1 | 13 | ... | | 0 | 18 | ... | | | 4 | 3 | 10 | 8 | 0 | 3 | 18 | 4 | 18 |
| ⅜... | 1 | 2 | 6 | 2 | 12 | 1 | 7 | 2 | 2 | ⅞... | 1 | 4 | 10 | 6 | 2 | 4 | 0 | 4 | 13 |
| | 2 | 2 | 4 | 2 | 11 | 1 | 8 | 2 | 2 | | 2 | 5 | 12 | 5 | 10 | 4 | 0 | 4 | 13 |
| | 3 | 2 | 4 | 2 | 16 | 1 | 10 | 2 | 2 | | 3 | 3 | 10 | 6 | 11 | 4 | 5 | 4 | 19 |
| | 4 | 2 | 0 | 2 | 10 | 1 | 13 | 2 | 0 | | 4 | 4 | 10 | 8 | 4 | 4 | 2 | 4 | 19 |
| ½... | 1 | 3 | 2 | 3 | 12 | 2 | 10 | 2 | 15 | 1... | 1 | 5 | 0 | 7 | 2 | 4 | 2 | 5 | 19 |
| | 2 | 3 | 4 | 4 | 0 | 1 | 17 | 3 | 10 | | 2 | 4 | 7 | 8 | 1 | 4 | 6 | 5 | 0 |
| | 3 | 3 | 0 | 4 | 0 | 2 | 2 | 3 | 1 | | 3 | 4 | 11 | 6 | 5 | 3 | 15 | 5 | 5 |
| | 4 | 2 | 10 | 4 | 0 | 2 | 5 | 2 | 15 | | 4 | 4 | 6 | 7 | 0 | 4 | 10 | 5 | 0 |
| ⅝... | 1 | 3 | 2 | 5 | 5 | 3 | 0 | 4 | 5 | | | | | | | | | | |
| | 2 | 3 | 0 | 4 | 8 | 3 | 6 | 3 | 18 | | | | | | | | | | |
| | 3 | 3 | 1 | 4 | 8 | 3 | 6 | 3 | 15 | | | | | | | | | | |
| | 4 | 3 | 1 | 5 | 0 | 2 | 9 | 3 | 5 | | | | | | | | | | |

† Drift is an allowance made to insure sufficient tightness in a fastening; it is therefore the quantity by which the diameter of a fastening exceeds the diameter of the hole bored for its reception.

"In Riga fir the adhesion was on an average about one third of that in oak, and in good sound Canada elm it was about three fourths of that in oak.

"*Table of the Strength of Clenches and of Forelocks, as securities to Iron and Copper Bolts, driven six inches, without Drift, into sound Oak, either clenched or forelocked on Rings, and subjected to a direct Strain, as in fig.* 57.

| Diameter of the Bolt. | Number of the Experiment. | Iron. |  |  |  | Copper. |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Clench. |  | Forelock. |  | Clench. |  | Forelock. |  |
| Inch. |  | Tons. | Cwt. | Tons. | Cwt. | Tons. | Cwt. | Tons. | Cwt. |
| ¼... | 1 | 1 | 18 | 8 | 18 | 1 | 0 | 8 | 8 |
|  | 2 | 1 | 13 | 0 | 14 | 8 | 19 | 8 | 8 |
|  | 3 | 1 | 9 | 0 | 20 | 1 | 0 | 8 | 7 |
|  | 4 | 1 | 9 | 0 | 18 | 1 | 0 | 0 | 8 |
| ⅜... | 1 | 3 | 0 | 1 | 15 | 2 | 10 | 1 | 4 |
|  | 2 | 3 | 0 | 1 | 8 | 2 | 10 | 1 | 0 |
|  | 3 | 2 | 16 | 1 | 8 | 2 | 5 | 1 | 2 |
|  | 4 | 2 | 15 | 1 | 14 | 2 | 9 | 1 | 4 |
| ½... | 1 | 4 | 15 | 2 | 11 | 3 | 10 | 1 | 18 |
|  | 2 | 4 | 18 | 2 | 15 | 3 | 15 | 1 | 16 |
|  | 3 | 4 | 5 | 2 | 18 | 4 | 0 | 2 | 4 |
|  | 4 | 4 | 12 | 2 | 12 | 4 | 10 | 1 | 16 |
| ⅝... | 1 | 5 | 18 | 3 | 15 | 6 | 0 | 2 | 13 |
|  | 2 | 6 | 8 | 3 | 8 | 5 | 15 | 2 | 10 |
|  | 3 | 8 | 3 | 3 | 8 | 8 | 5 | 2 | 18 |
|  | 4 | 8 | 8 | 3 | 7 | 5 | 18 | 2 | 10 |
| ¾... | 1 | 7 | 10 | 3 | 18 | 7 | 0 | ... |  |
|  | 2 | 7 | 10 | 3 | 15 | 7 | 0 | ... |  |
|  | 3 | 8 | 8 | 3 | 18 | 7 | 5 | ... |  |
|  | 4 | 8 | 15 | 3 | 15 | 7 | 8 | ... |  |
| ⅞... | 1 | 11 | 11 | 5 | 1 | 7 | 16 | ... |  |
|  | 2 | 11 | 15 | 5 | 18 | 7 | 18 | ... |  |
|  | 3 | 8 | 11 | 4 | 6 | 7 | 12 | ... |  |
|  | 4 | 8 | 8 | 4 | 15 | 7 | 5 | ... |  |
| 1... | 1 | 12 | 8 | 5 | 16 | 7 | 1 | ... |  |
|  | 2 | 12 | 3 | 6 | 18 | 7 | 1 | ... |  |
|  | 3 | 11 | 3 | 5 | 12 | 7 | 14 | ... |  |
|  | 4 | 11 | 1 | 5 | 2 | 8 | 14 | ... |  |

"In the experiments on the clenches, the clenches always gave way; but with the forelocks it as frequently occurred that the forelock was cut off as that the bolt broke; and in the cases of the bolt breaking, it was invariably across the forelock hole. According to the tables, the security of a forelock is about half that of a clench.

"It appears an anomaly that the strength of a clench on copper should be equal to that of one on iron. But, in consequence of the greater ductility of copper, a better clench is formed on it than on iron. Generally the thickness of the fractured clench in the copper was double that in the iron. With rings of the usual width for the clenches, the wood will break away under the ring, and the ring be imbedded for two or more inches before the clench will give way.

"With the inch copper bolts, all the rings under the clenches turned up into the shape of the frustum of a cone, and allowed the clench to slip through at the weights specified.

"Experiments with ring-bolts were made to ascertain the strength of the rings in comparison with the clenches. The rings were of the usual size, viz. the iron of the ring one eighth inch less in diameter than that of the bolt. It was found that the rings always carried away the clenches, but that they were drawn into the form of a link with perfectly straight sides. The rings bore, before any change of form took place, not quite one half the weight which tore off the clenches. It appears that the rings are well proportioned to the strength of the clenches.

"*Table of the Transverse Strength of Treenails of English Oak used as fastening for Planks of three and of six inches in thickness, and subjected to a Strain, as shown to be applied in fig.* 58.

| Number of the Experiment. | Diameter of the Treenails. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 Inch. |  |  |  | 1¼ Inch. |  |  |  | 1½ Inch. |  |  |  | 1¾ Inch. |  |  |  |
|  | Thickness of the Plank. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 3 In. |  | 6 In. |  | 3 In. |  | 6 In. |  | 3 In. |  | 6 In. |  | 3 In. |  | 6 In. |  |
|  | T. | C. | T. | C. | T. | C. | T. | C. | T. | C. | T. | C. | T. | C. | T. | C. |
| 1 | 1 | 8 | 1 | 7 | 1 | 14 | 2 | 8 | 2 | 0 | 3 | 12 | 3 | 0 | 5 | 10 |
| 2 | 1 | 7 | 1 | 15 | 2 | 2 | 2 | 2 | 2 | 6 | 2 | 18 | 2 | 10 | 3 | 13 |
| 3 | 1 | 2 | 1 | 8 | 1 | 17 | 2 | 19 | 2 | 15 | 2 | 10 | 4 | 0 | 4 | 8 |
| 4 | 1 | 5½ | 1 | 8 | 2 | 2 | 2 | 2 | 2 | 4 | 3 | 12 | 2 | 8 | 3 | 8 |
| 5 | 2 | 12 | 1 | 3 | 2 | 2 | 1 | 15 | 2 | 18 | 2 | 5 | 3 | 18 | 4 | 0 |
| 6 | 2 | 2 | 1 | 7 | 2 | 9 | 2 | 18 | 2 | 6 | 2 | 5 | 3 | 10 | 5 | 8 |
| 7 | 2 | 4 | 1 | 18 | 2 | 6 | 2 | 18 | 3 | 7 | 2 | 5 | 3 | 5 | 3 | 12 |
| 8 | 1 | 6 | 2 | 3 | 2 | 7 | 2 | 8 | 2 | 5 | 3 | 0 | 3 | 5 | 3 | 13 |
| 8 | 1 | 8 | 1 | 8 | 2 | 12 | 2 | 18 | 3 | 8 | 4 | 8 | 4 | 8 | 4 | 13 |
| 18 | 1 | 2 | 2 | 3 | 2 | 10 | 2 | 16 | 3 | 0 | 4 | 10 | 3 | 8 | 4 | 0 |
| 11 | 2 | 8 | 2 | 0 | 2 | 7 | 2 | 0 | 3 | 8 | 2 | 18 | 4 | 0 | 3 | 8 |
| 12 | 1 | 8 | 1 | 7 | 2 | 10 | 2 | 6 | 4 | 2 | 3 | 0 | 4 | 18 | 5 | 8 |
| 13 | 1 | 18 | 2 | 8 | 2 | 17 | 2 | 8 | 3 | 2 | 3 | 18 | 4 | 2 | 5 | 5 |
| Average | 1 | 11 | 1 | 13 | 2 | 8 | 2 | 8 | 2 | 16 | 3 | 2 | 3 | 10 | 4 | 8 |

"In all these experiments on treenails, when the treenails were evidently good, they gave way gradually. In some of the rejected experiments, however, the treenails certainly did break off suddenly, but then they were evidently on examination either bad or over-seasoned treenails. It is no uncommon remark in caulking down the bottom of a vessel, that the caulkers break off the treenails by caulking, and that they hear them crack or break off suddenly. Now I do not believe that this cracking of the treenails takes place so frequently as it is supposed. What the men hear is the starting of the plank on the different fastenings. It has been asserted that the treenails made from the Sussex oak are much stronger than those made from the New Forest timber, or any other English oak. To ascertain the truth of this assertion, some experiments were made with Sussex and New Forest treenails of all sizes; and the result was, that there was not the least difference in them, the New Forest were on experiment quite as strong as the Sussex.

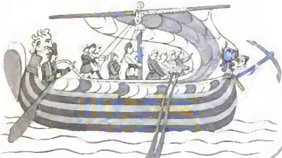
"In the experiments on treenails, the plank generally moved about half an inch previous to the fracture of the treenail." (B. Z.)

THE

Edinburgh.

# SHIP-BUILDING.

*PLATE CCCCXLV.*



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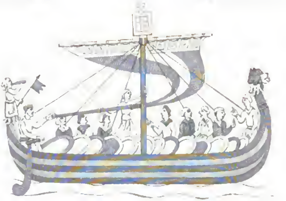

[illegible]

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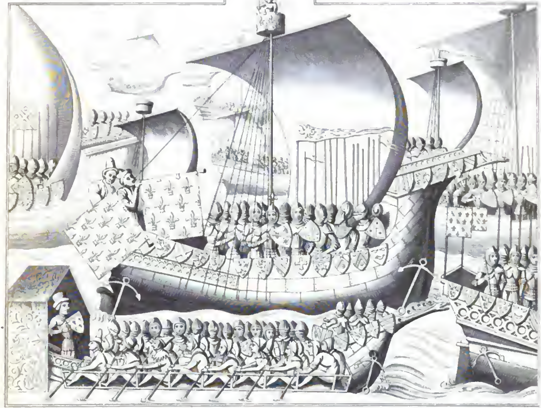
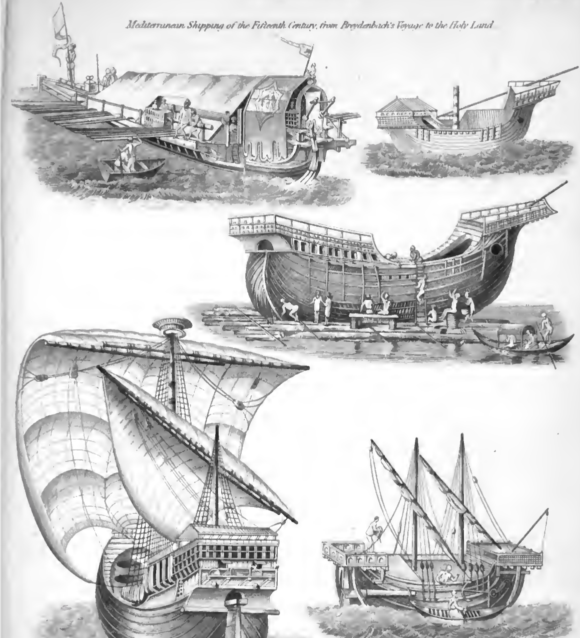


[illegible]

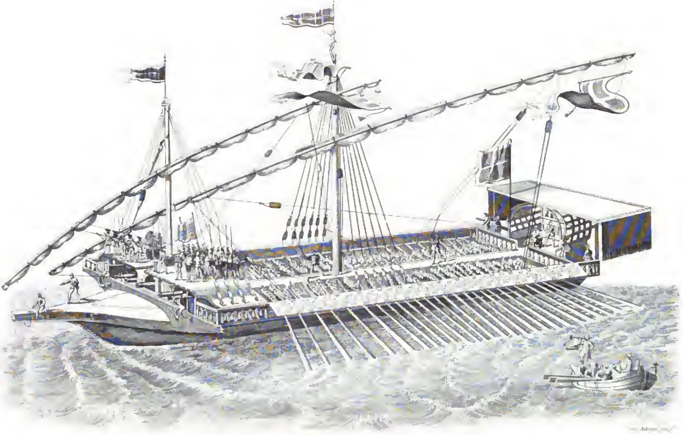
# SHIP-BUILDING.

PLATE CCCCXLVI.

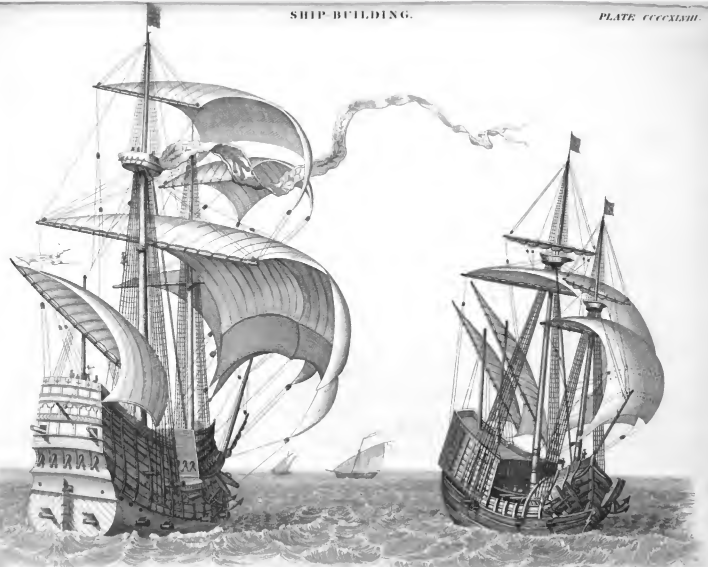
*Mediterranean Shipping of the Fifteenth Century, from Breydenbach's Voyage to the Holy Land.*



Geo. Aikman, Sculpt



*Galley of the Seventeenth Century from Van Yk.*



Carracks, Galleons or Tall Shipps of the Seventeenth Century, from Van Yk

Geo Aikman, Sculpt

# SHIP-BUILD

## DRAUGHT OF HER MAJESTY'S

*Dimensions*

| | | |
|---|---|---|
| Length of Gun Deck | 176 ft | 4 ins |
| Length of Keel for Tonnage | 145 | 7¾ |
| Breadth extreme | 47 . | 10¼ |
| Depth in Hold | 14 . | 4 |
| Burthen in Tons. 1775 N° | | |

Main D

Quarter

& Fore

STERN

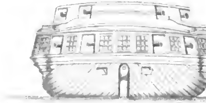
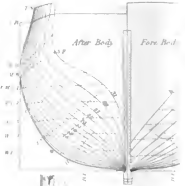


Fig 25

BODY PLAN



Fig

SHEER

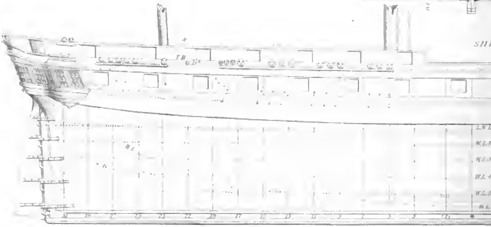
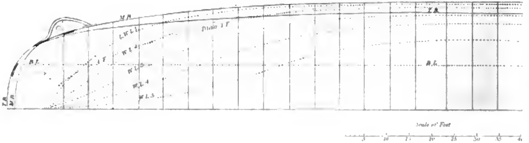


Fig 26

HALF BREADTH PLAN

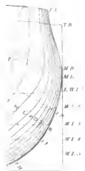


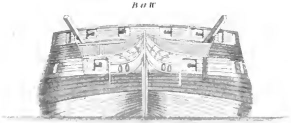
FRIGATE VINDICTIVE.

*Armament*

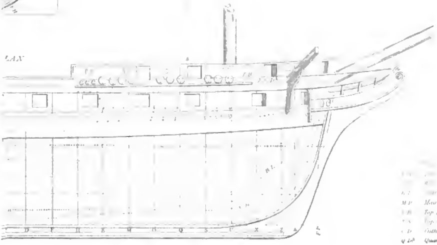
6 N° 8 inch 65 Cwt 9 f. 0 ins in Length
22 32 prs 56 9 6

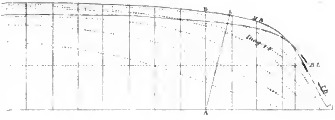
22 32 prs 45 8 6





LAN





| | |
|---|---|
| [illegible] | [illegible] |
| L W L | Load Water Line |
| W L | Water Lines |
| B L | Butt^k & Bow Lines |
| M B | Main Breadth |
| T B | Top Breadth |
| T S | Top side |
| C D | Cutting down |
| Q D^k | Quarter Deck |
| F C D^k | Fore castle D° |
| U D^k | Upper D° |
| L D^k | Lower D° |
| F P | Fore Perpendicular |
| A P | After D° |
| F H | Floor Head |
| 1 F | 1^st Futtock D° |
| 2 F | 2^nd Futt^k D° |
| 3 F | 3^rd Futt^k D° |

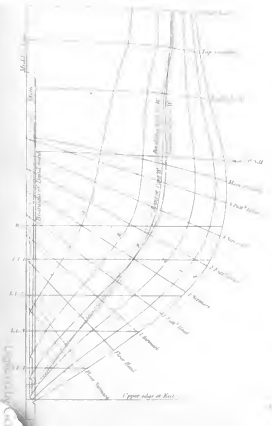
[illegible]

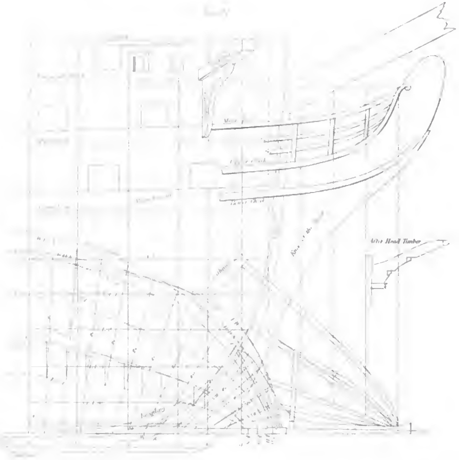
# SHIP-BUILDING.

PLATE CCCCLI.

## LAYING OFF

Fig. 2[illegible]





Geo. Aikman, Sculp^t

LAYING OFF

Fig. 30

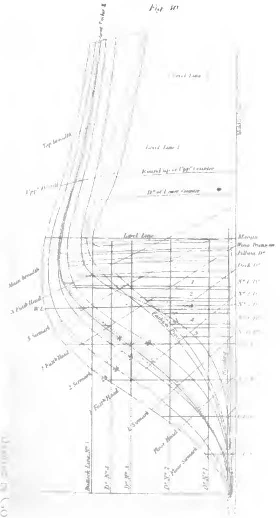
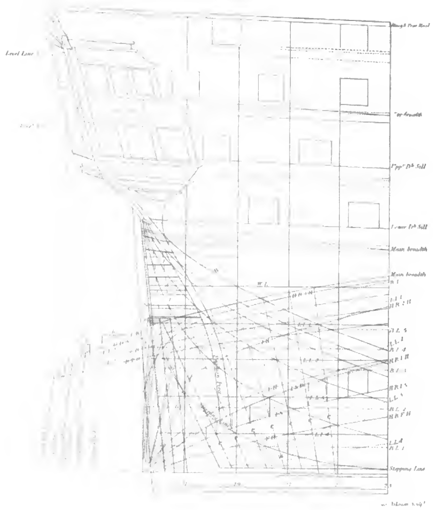


Fig 29



Wilson sculp^t

LAYING OFF

Fig 33

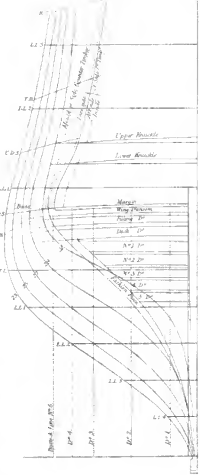


Fig 32

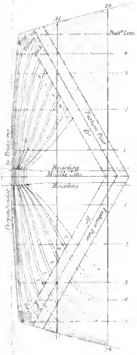


Fig 31

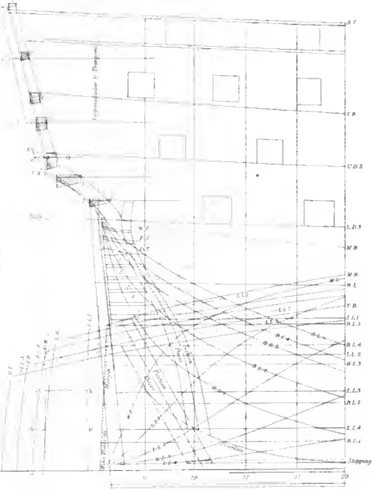
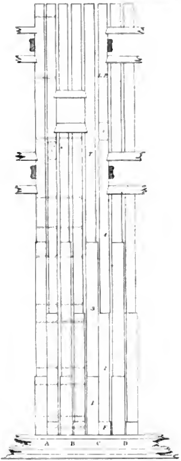


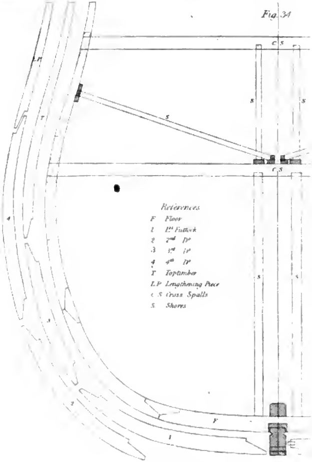
Fig. 35

Old Plan



Midship Sections, showing Plans

Fig. 34



References

F Floor

1 1st Futtock

2 2nd Do

3 3rd Do

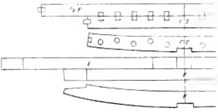
4 4th Do

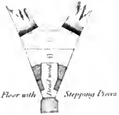
T Toptimber

L.P Lengthening Piece

C.S Cross Spalls

S Shores





Made Floor with Stepping Pieces

Fig. 37

Lang's Safety Keel

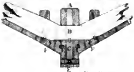


Fig. 39

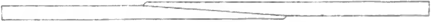
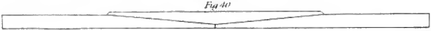
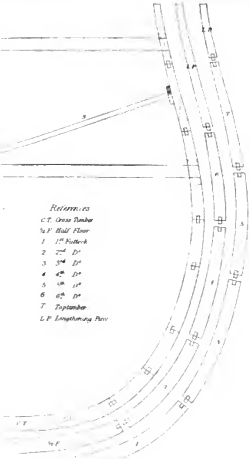


Fig. 40



*Timbering Ships*

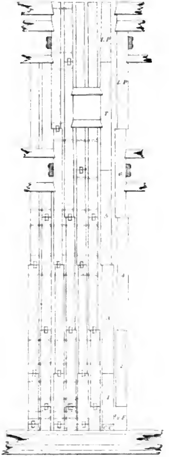
*Modern Plan*



*References*

| | |
|---|---|
| C.T. | Cross Timber |
| ½ F | Half Floor |
| 1 | 1st Futtock |
| 2 | 2nd D° |
| 3 | 3rd D° |
| 4 | 4th D° |
| 5 | 5th D° |
| 6 | 6th D° |
| T | Toptimber |
| L.P | Lengthening Piece |

*Fig 36*



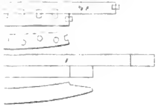
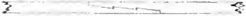
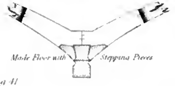


*Fig 38*

*Edye's Beam*





*Made Floor with Stepping Pieces*

*Fig 41*

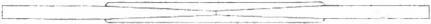
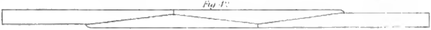
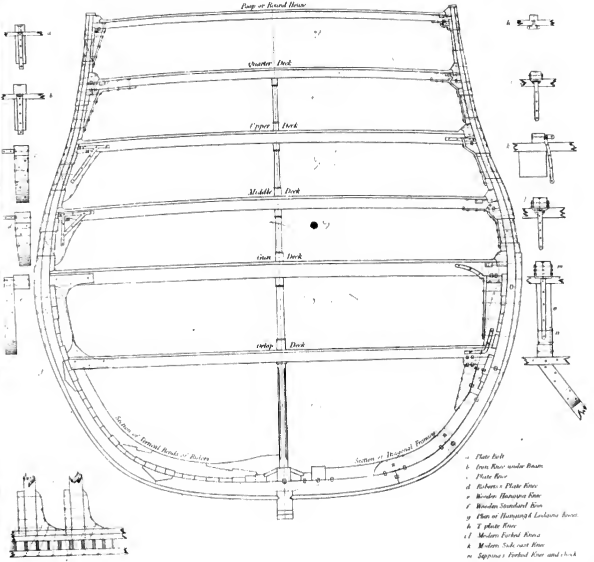


*Fig 42*

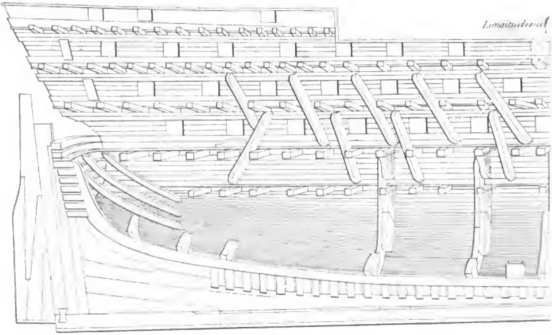


*Section of a First Rate Ship of War; showing the various Plans which have been adopted for securing the Beam ends to the side, together with those at present in use*

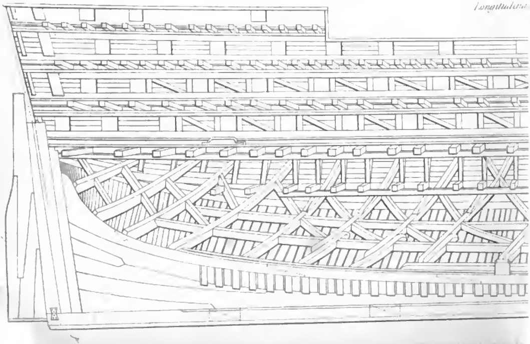


*a* Plate Bolt
*b* Iron Knee under Beam
*c* Plate Knee
*d* Roberts's Plate Knee
*e* Wooden Hanging Knee
*f* Wooden Standard Knee
*g* Plan of Hanging & Lodging Knees
*h* T plate Knee
*i l* Modern Forked Knees
*k* Modern Side cast Knee
*m* Seppings's Forked Knee and chock
*n* Side Plate

Longitudinal



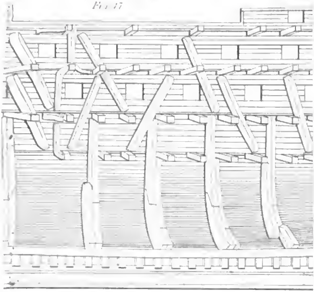
Longitudina



# SHIP BUILDING.

Section of a Ship according to the Old System of Building

Fig. 17



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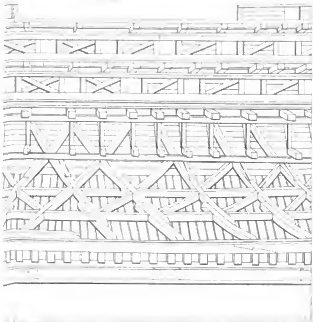
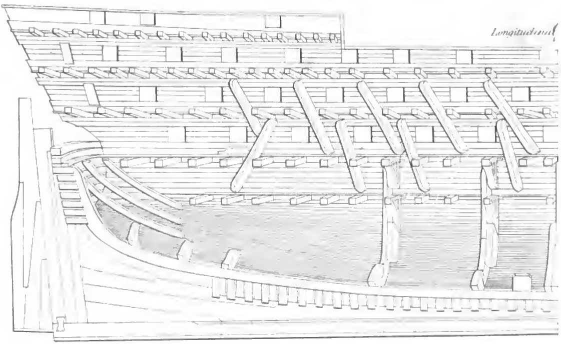
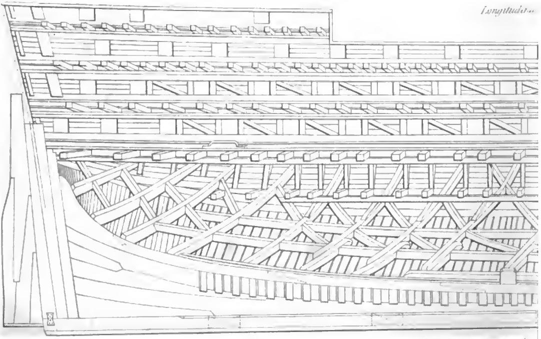




Longitudinal

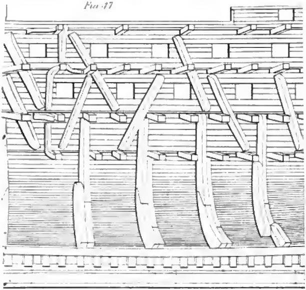


Longitudina

# SHIP BUILDING.

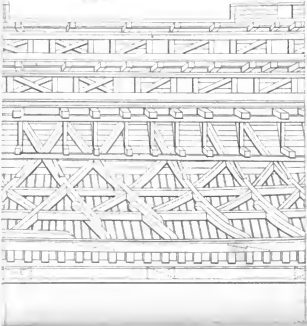
*Section of a Ship according to the Old System of Building*

*Fig. 47*



[illegible]

*Fig. 48*



# SHIP BUILDING.

Fig 49

*Modern Disposition of the Timbers of an English Line of Battle Ship, with a Plan of the Modern System of Diagonal Trussing with Iron Plates*

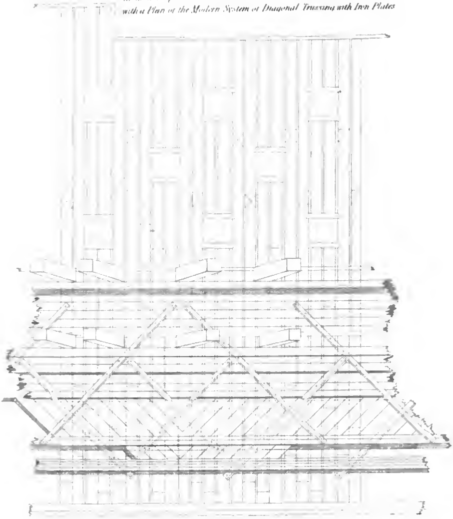


Fig 50

*Disposition of the Timbers of a French Line of Battle Ship*

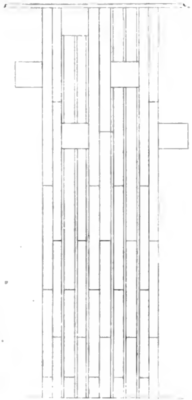
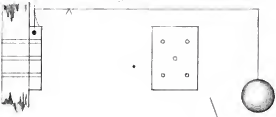
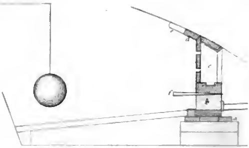


Fig 58





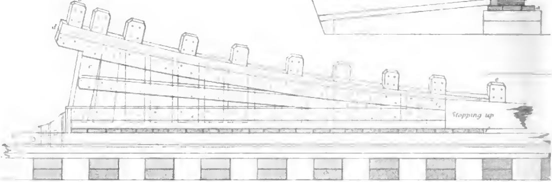


Fig 52

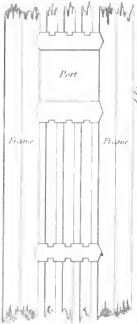
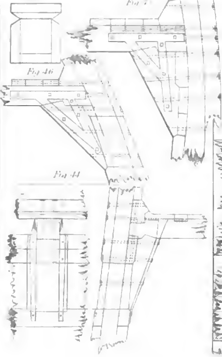


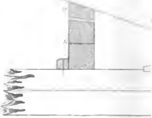
Fig 51

Fig [illegible]

Fig 46

Fig 44





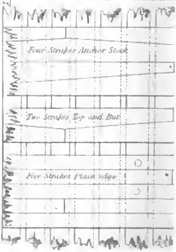


Fig 53

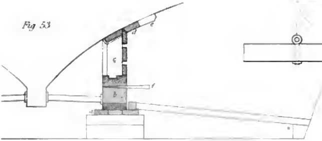


Fig 57

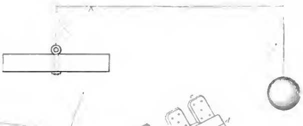


Fig 54

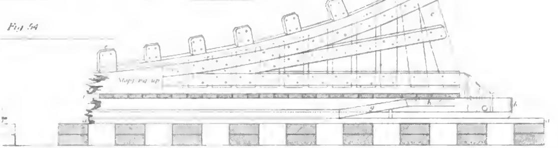


Fig 55

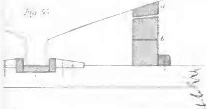


Fig 56

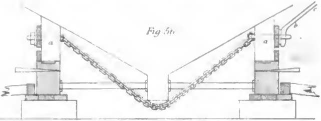
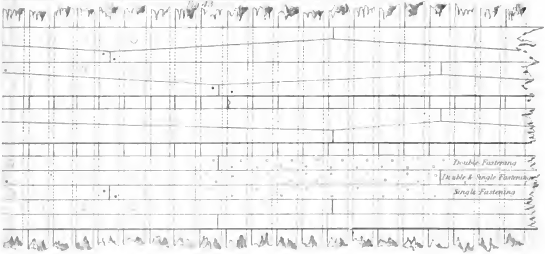


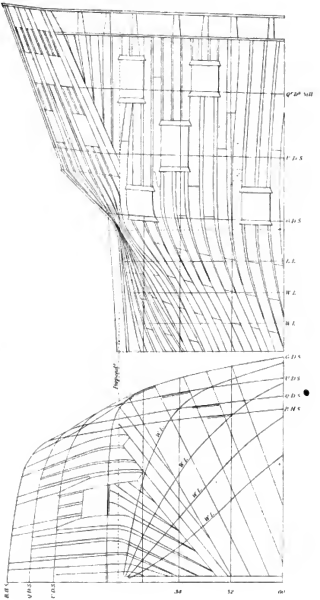
Fig 58



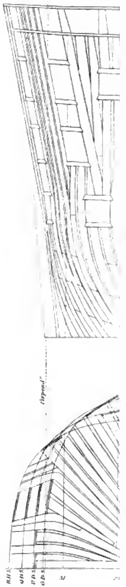
# SHIP-BUI

## *Methods of Timbering Square*

*Modern Elliptical Stern.*

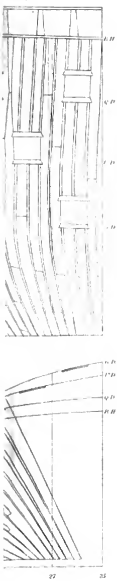


*Circula*

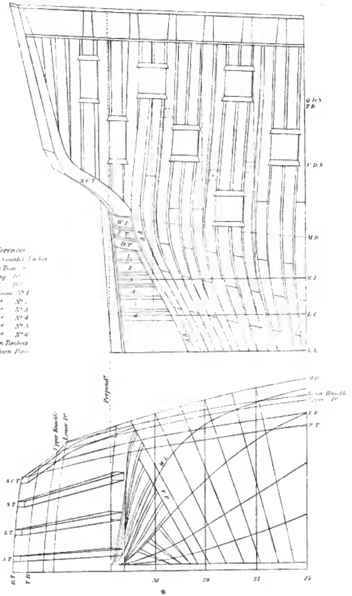


## Circular & Elliptical Sterns.

### Stern.



### Square Stern



References

| | |
|---|---|
| S C T | Side counter Timber |
| W T | Wing Transom |
| F T | Filling D^o |
| D T | Deck D^o |
| 1 | Transom N^o 1 |
| 2 | D^o N^o 2 |
| 3 | D^o N^o 3 |
| 4 | D^o N^o 4 |
| 5 | D^o N^o 5 |
| 6 | D^o N^o 6 |
| S T | Stern Timbers |
| F P | Fashion Piece |

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